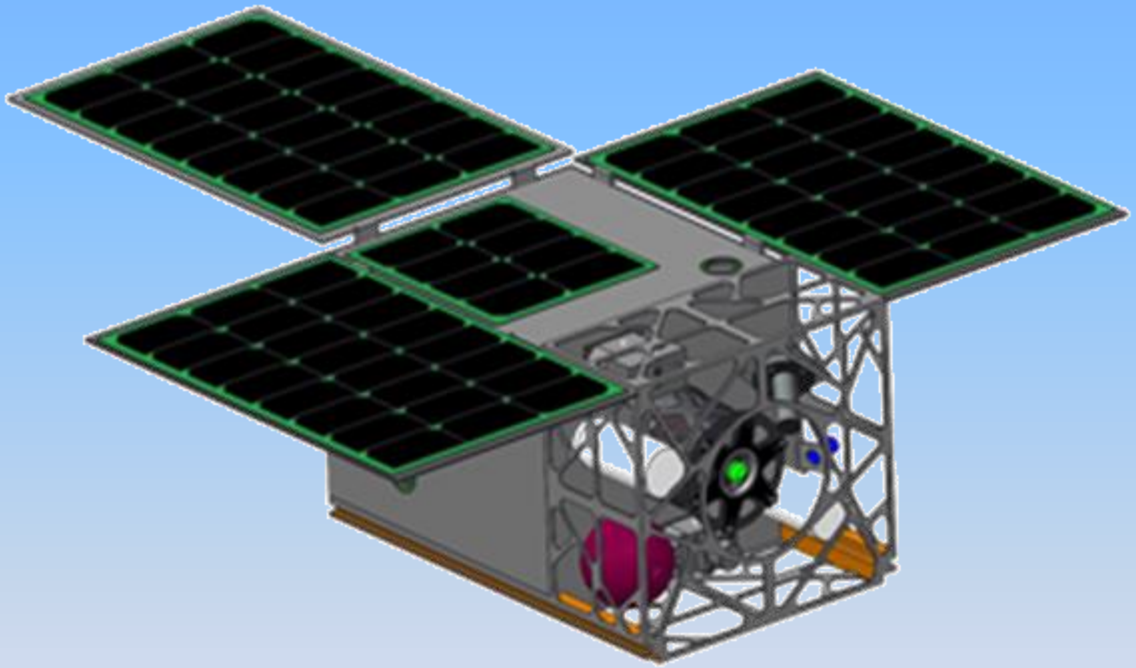
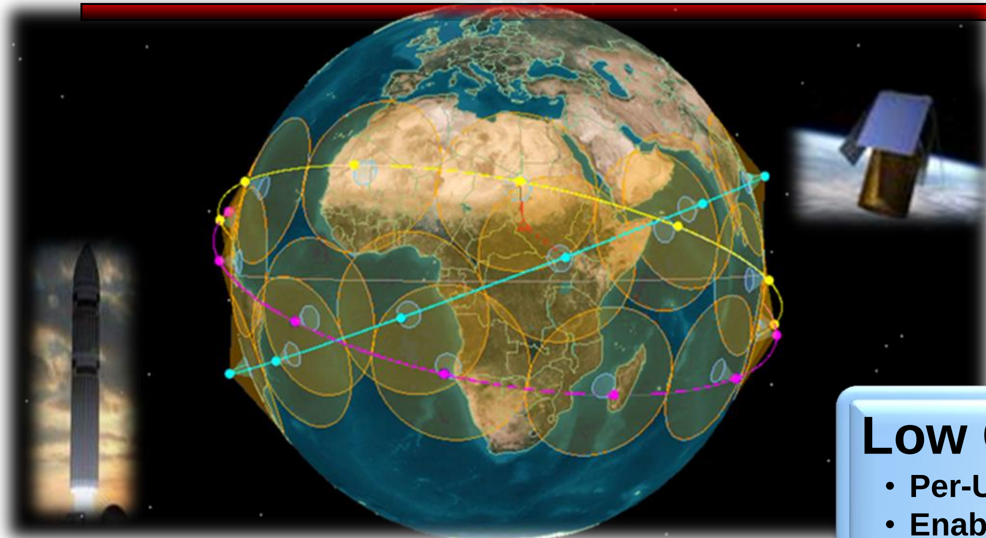
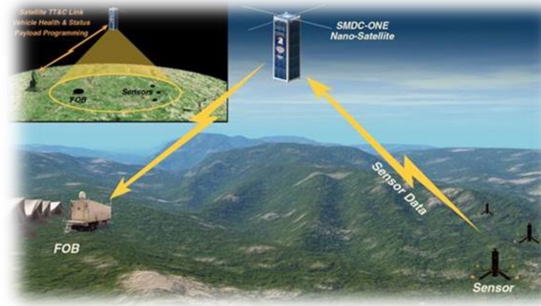
The iodine Satellite (iSAT): Enabling SmallSat Maneuverability



Aerospace Corporation Seminar
October 9, 2014

SmallSat Applications – USASMDC / ARSTRAT



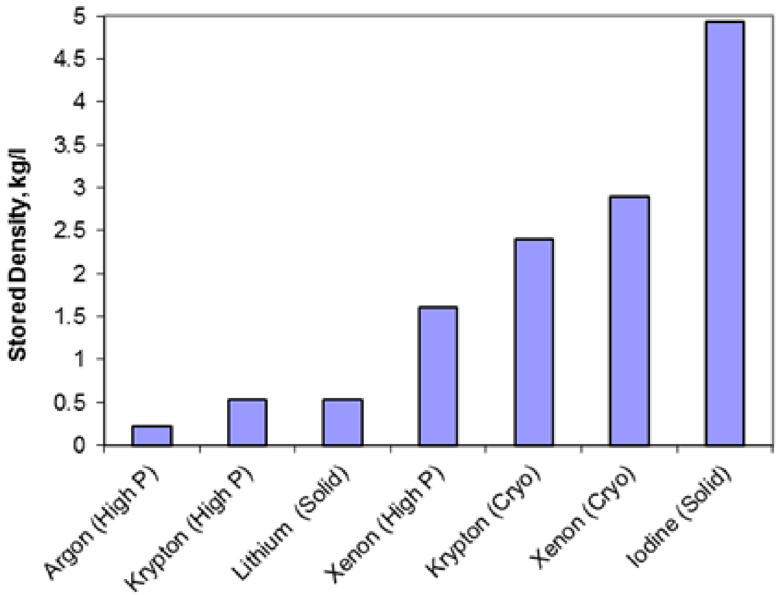


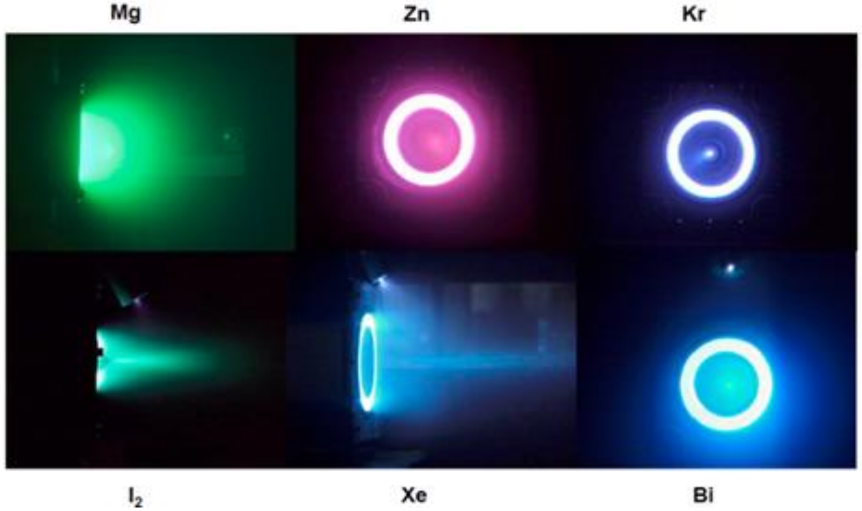
Low Cost
- Per-Unit Cost Very Low
- Enables Affordable Satellite Constellations
- Minimal Personnel and Logistics Tail
- Frequent Technology Refresh

Survivability
- Fly Above Threats and Crowded Airspace
- Rapid Augmentation and Reconstitution
- Very Small Target

Responsiveness
- Short-Notice Deployment
- Tasked from Theater
- Persistent and Globally Available
- Can Adapt to the Threat

Iodine vs. Alternatives





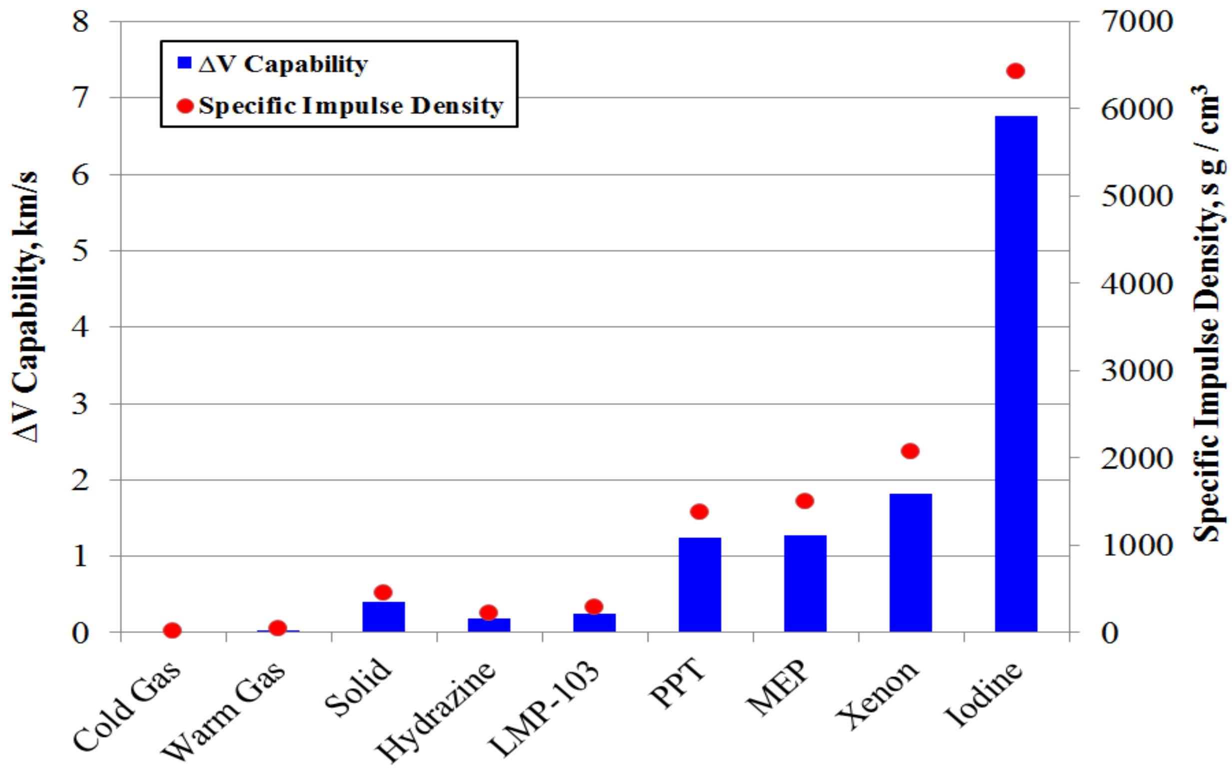
Propellant	Storage Density	Boiling Point, ºC	Melting Point, ºC	Vapor Pressure @ 20ºC
Xe (SOA)	1.6 g/cm^3	-108.1 ºC	-111.8 ºC	Supercritical (>15MPa)
Iodine	4.9 g/cm^3	184.3 ºC	113.7 ºC	40 Pa (0.0004 atm)
Bismuth	9.8 g/cm^3	1,564 ºC	271.4 ºC	Solid
Magnesium	1.74 g/cm^3	1,091 ºC	650 ºC	Solid

Iodine has unique characteristics well suited for mission application

Microsatellite Advantages

Primary mission advantages are due to 1) Increased I_{SP} * Density

2) Low storage pressure

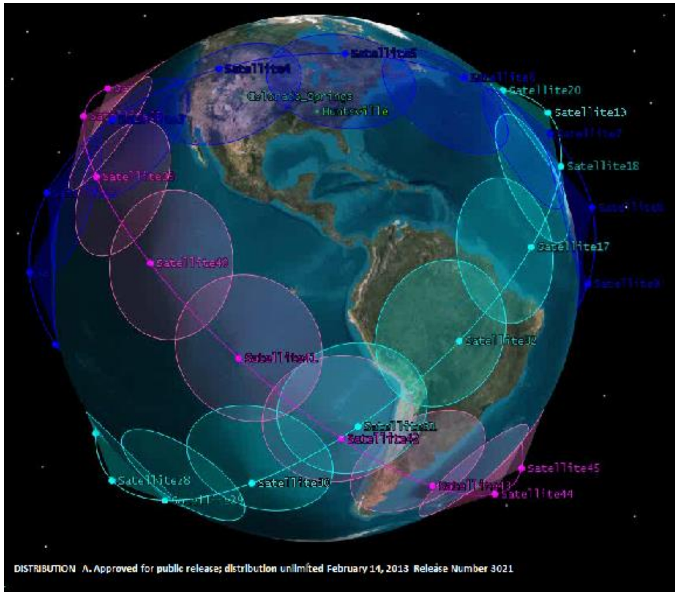


Microsatellites are extremely volume constrained

Geocentric MicroSat Application

Large increase in demand for MicroSat constellations and responsive space capabilities.

- The 12U with 5kg of iodine can perform 4km/s ΔV
    - 20,000km altitude change
    - 30^{o} inclination change from LEO
    - 80^{o} inclination change from GEO
- Larger spacecraft can perform even greater ΔV



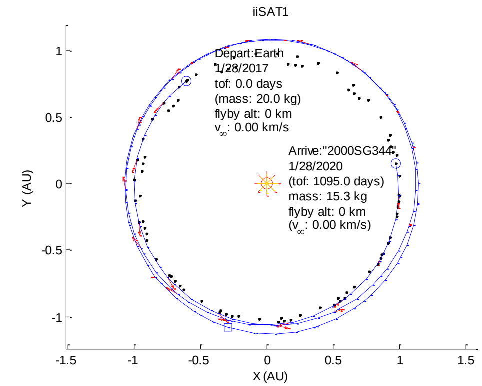
iSAT Mass Estimation List - 12U LEO		Basic Mass (kg)	MGA (%)	MGA (kg)	Predicted Mass (kg)
1.0	Structures	1.601	30%	0.480	2.081
2.0	Mechanisms	0.100	30%	0.030	0.130
3.0	Thermal	0.334	30%	0.100	0.434
4.0	Power	2.052	30%	0.616	2.668
5.0	Guidance Navigation & Control	1.518	10%	0.152	1.670
6.0	Communications	0.090	6.00%	0.005	0.095
7.0	Command and Data Handling	0.324	16%	0.053	0.377
8.0	Propulsion	3.846	25%	0.965	4.811
Dry Mass		9.864	24%	2.401	12.265
9.0	Payload	2.000	30%	0.600	2.600
10.0	Non-Propellant Fluids	0.000	0%	0.000	0.000
Inert Mass		11.864	25%	3.001	14.865
11.0	Propellant (Solid Iodine)	5.135		0.000	5.135
iSAT 12U LEO Total Mass		16.999		3.001	20.000

Iodine in enabling for rapidly growing spacecraft market.

Interplanetary MicroSat

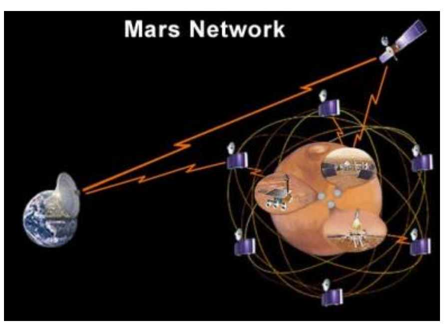
NASA is pursing interplanetary MicroSat missions

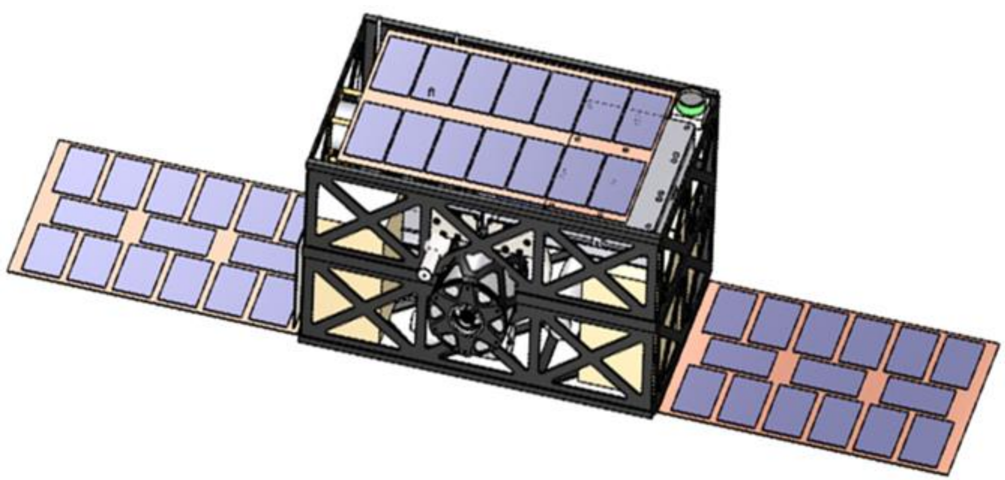
- INSPIRE selected as first interplanetary CubeSat – no propulsion
- NASA HEOMD AES funding NEA Scout – solar sail propulsion
- High pressure and hazardous propellants are not allowed



Iodine on an interplanetary CubeSat can provide ~2.5km/s of ΔV

- Challenges with communications and attitude control over geocentric spacecraft
- Enables asteroid flyby and rendezvous missions for <$20M life cycle cost
- Enables secondary missions via primary host deployment
    - Outer planet moons
    - Constellations



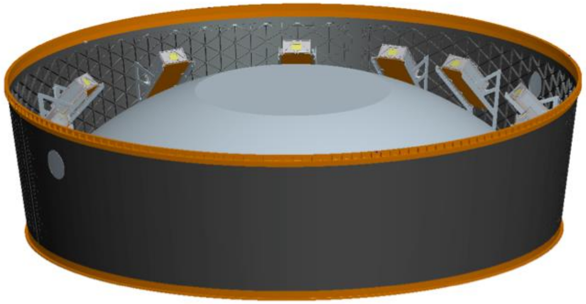


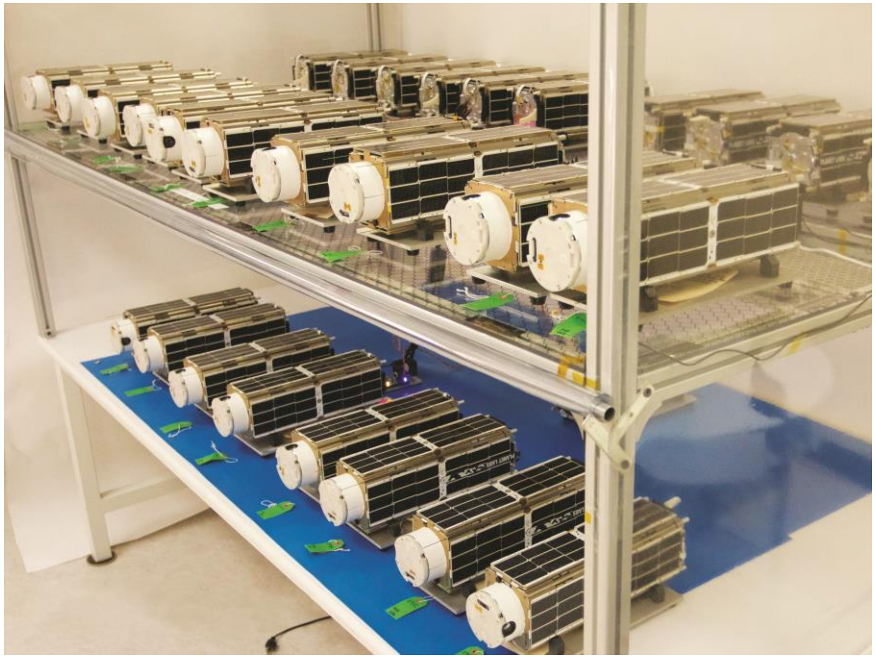
Iodine enables high ΔV interplanetary propulsion

NASA Launch Opportunities

NASA benefits from a wide range of launch opportunities:

- Excess launch mass from NASA missions
- Excess mass to ISS
- Secondary payloads from SLS



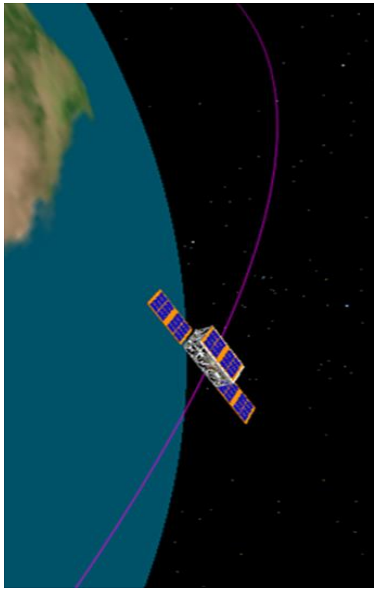


Iodine enables full utilization of NASA launch opportunities.

iSAT Mission Concept Overview

The iSAT Project is the maturation of iodine Hall technology to enable high ΔV primary propulsion for NanoSats (1-10kg), MicroSats (10-100kg) and MiniSats (100-500kg) with the culmination of a technology flight demonstration.

- NASA Glenn is leading the technology development and is the flight propulsion system lead
    - Busek delivering the qualification and flight system hardware
- NASA MSFC is leading the flight system development and operations



The iSAT Project launches a small spacecraft into low-Earth orbit to:

- Validate system performance in space
- Demonstrate high ΔV primary propulsion
- Reduce risk for future higher class iodine missions
- Demonstrate new power system technology for SmallSats
- Demonstrate new class of thermal control for SmallSats
- Perform secondary science phase with contributed payload
    - Increase expectation of follow-on SMD and AF missions
- Demonstrate SmallSat Deorbit
- **Validate iodine spacecraft interactions / efficacy**

High value mission for SmallSats and for future higher-class mission leveraging iodine propulsion advantages.

iSAT Project Overview

Mission Justification

There is an emerging and rapidly growing market for SmallSats

- SmallSats are significantly limited by primary propulsion
  - Desire to transfer to higher value science / operations orbit and responsive space
  - Desire to extend mission life / perform drag make-up
  - Requirement to deorbit within 25 years of end-of-mission

Limitations on SmallSats limit primary propulsion options

- Requirements imposed by nature of secondary payloads
  - Limitations for volume, mass and power
  - Limitations on hazardous and stored energy from propellants
  - Limitations for high pressure systems
  - Systems must sit quiescent for unknown periods before integration with primary

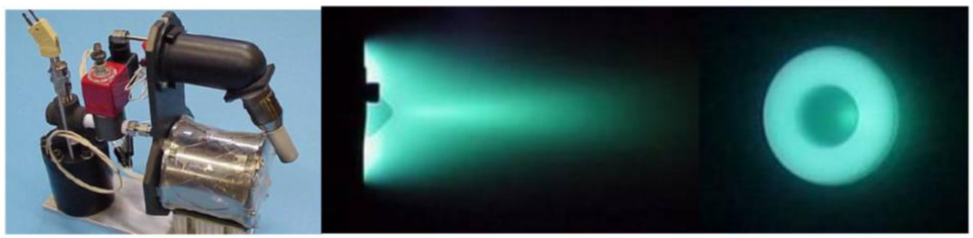
Why perform flight validation?

- Reduce risk of implementation of iodine for future higher class missions
- Gain experience with condensable propellant spacecraft interactions
- Reduce risk of custom support systems
  - Power generation, storage and distribution
  - Thermal control
- Cost effective risk reduction before maturing higher power systems

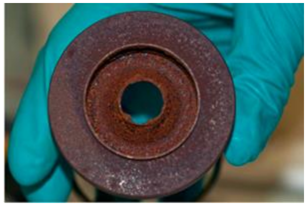
iSAT Project Overview

Mission Justification

- **200W NanoSat infusion near-term with low entry cost and lower risk**
  - Short mission durations, low throughput requirement, simple propellant management
  - Engineering / material changes and validation, valve wetting surfaces and seals
  - Demonstrates enabling technology, demonstrates high spacecraft power density



- **Additional high payoff for higher power / high payoff mission infusion**
  - Critical Technology Gaps and Risks Remain
    - Propellant flow rate and metering is critical to achieve required performance
    - Large propellant management, potentially conformal tanks
      - Uniform / efficient heating and propellant management critical
    - Wear testing >1000hrs for both thrusters and cathodes
    - Additional material compatibility testing
    - Spacecraft / plume interactions testing and analyses
    - Sputter erosion data, erosion modeling and lifetime analyses



Critical gaps remain for efficient propellant heating, transport and metering in a relevant environment in addition to long duration test data and analyses required for mid-term mission infusion.

iSAT Project Overview

Stakeholder Expectations

The iSAT project is supported by a wide range of customers including:

- MSFC Technology Investment Program (TIP)
- MSFC Center Strategic Development Steering Group (CSDSG)
- Science Mission Directorate (SMD) Directed Research and Technology (DR&T)
- Office of the Chief Technologist (OCT)
- Advanced Exploration Systems (AES) Program
- Game Changing Development (GCD) Program
- NASA Engineering and Safety Center (NESC)
- Air Force Research Laboratory – Operationally Responsive Space (ORS)
- Small Business Innovative Research (SBIR) Program

Additional stakeholders include:

- NASA Glenn to transition a new Electric Propulsion technology to flight
- NASA MSFC to provide flight system development experience to young engineers
- SmallSat Program to enable new capabilities for future SmallSat missions
- Future commercial contractors (ULA, Northrop Grumman, NanoRacks, etc.)
- Busek, the Small Business with the IP for the iodine Hall system
- Far-term users for high power iodine Hall systems

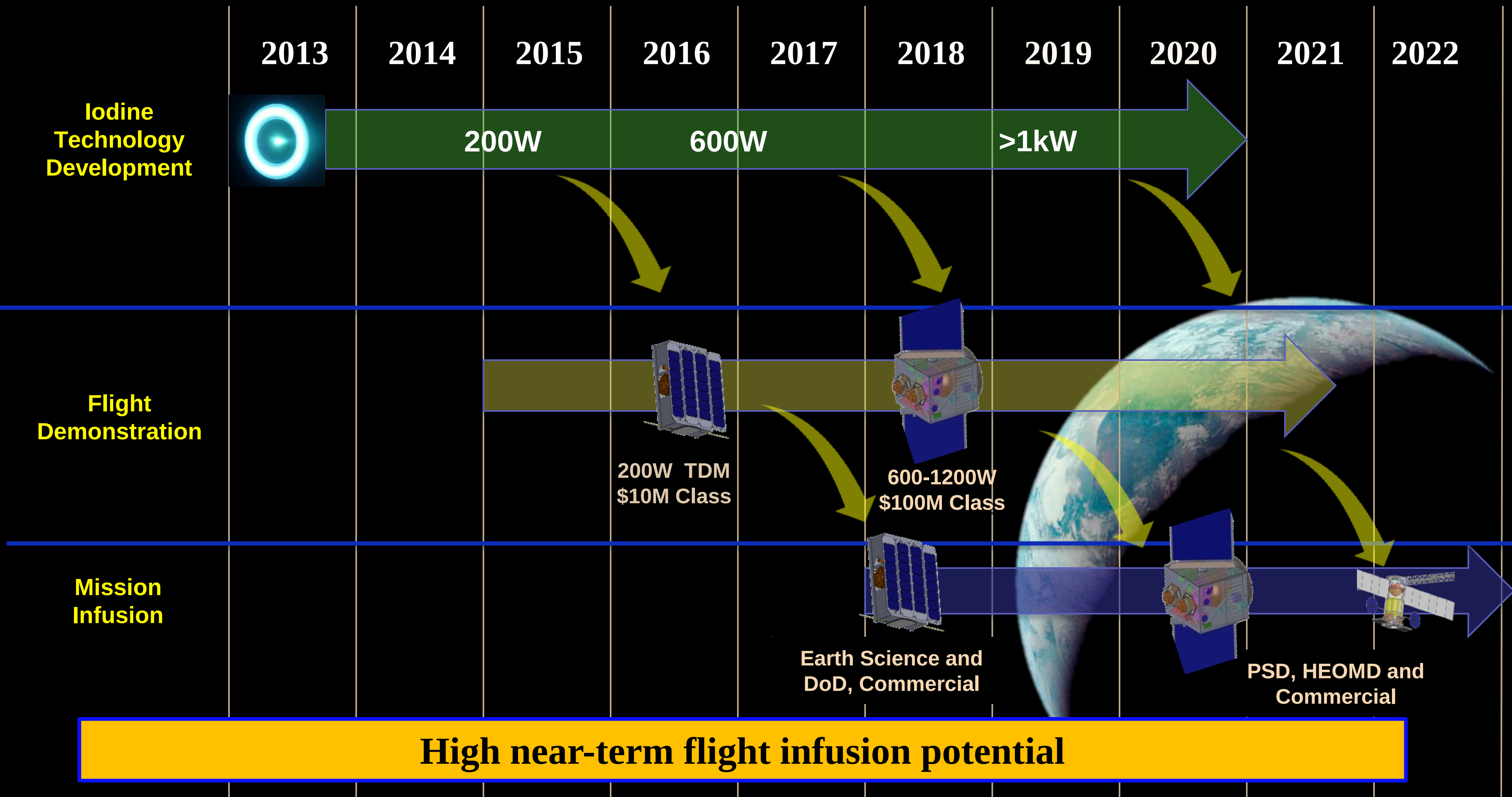
Targeted stakeholder:

- STMD: SmallSat Program or Technology Demonstration Mission (TDM) program

iSAT Project Overview

Mission Justification

- **High applicability at a range of power levels**
  - 200W System: (10-20kg S/C) – LEO maneuverability, constellations and de-orbit – Launch <$1M
  - 600W+ System (100 – 300kg S/C) – New class of interplanetary missions – Launch < $20M



High near-term flight infusion potential

iSAT Project Overview

Mission Justification – Launch Vehicle Savings

	Containerized Payloads				MicroSat Class		
Payload Class	1U	3U	6U	12U	50 kg	180 kg	300 kg
Length (cm)	10.0	34.0	36.6	36.6	80	100	125
Height (cm)	10.0	10.0	10.0	22.6	40	60	80
Width (cm)	10.0	10.0	22.6	22.6	40	60	80
Mass (kg)	1.0	5.0	10.0	20.0	50	180	300
Low Earth Orbit (LEO)	$125k	$325k	$595k	$995k	$1,750k	$4,950k	$6,950k
Geosynchronous Transfer Orbit (GTO)	$250k	$650k	$995k	$1,950k	$3,250k	$7,950k	$9,960k
Geosynchronous / Low Lunar Orbit (GSO/LLO)	$490k	$995k	$1,990k	$3,250k	$6,500k	$15,900k	$19,900k

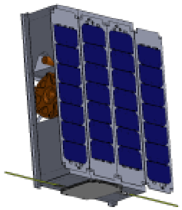
Secondary SmallSats can reduce launch costs by >90%.

Iodine enables interplanetary SmallSats from GTO.

Mid-Term Iodine Objectives

Multiple Studies Completed on Enabling Applications:

1) 200 W Iodine is enabling for NanoSats (1-10kg) and MicroSats (10-100kg)



- Iodine properties are ideal for secondary payloads

- Benign propellant, quiescent until heated

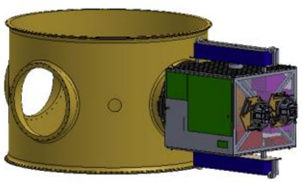
- Launches and stores unpressurized

- High density ~6g/cm^3 and high Density – I_{SP} ~ 8,000 g-s/cm^3

- Xe ~3,000 g-s/cm^3, Solid Motor ~500 g-s/cm^3, Cold Gas ~150 g-s/cm^3

- Enables orbit maneuverability (plane change and altitude change)

- Enables spacecraft deorbit



2) 200W – 600W Iodine enables very high ΔV for ESPA class (180kg) spacecraft

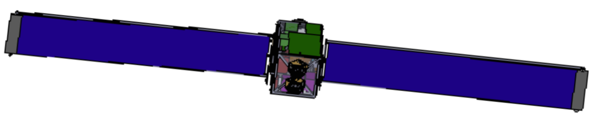
- Can provide ~10km/s ΔV

- More than 2x the Xenon ΔV capability (Volume limited)

- Enables GTO to Asteroids, Mars and Venus (Iodine and Xenon can both go to the moon)

3) 600W Iodine Enables "Discovery Class" Science Instruments for ESPA Grande class (300kg) spacecraft

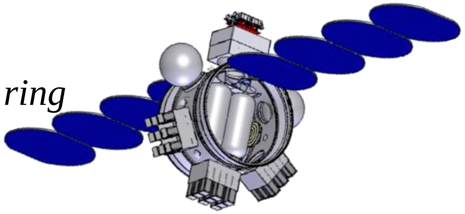
- Volume limitations require high density propellant



- 3x – 5x reduction in total mission cost

- New class of HEOMD and SMD missions

4) 600W – 1.5KW Class Iodine Enables Orbit Maneuvering Systems



- Iodine based ESPA OMS can enable high ΔV using the volume within the ESPA ring

- Can enable additional payloads over Xenon from GTO to GEO

- Can enable independent payload delivery to various Mars orbits

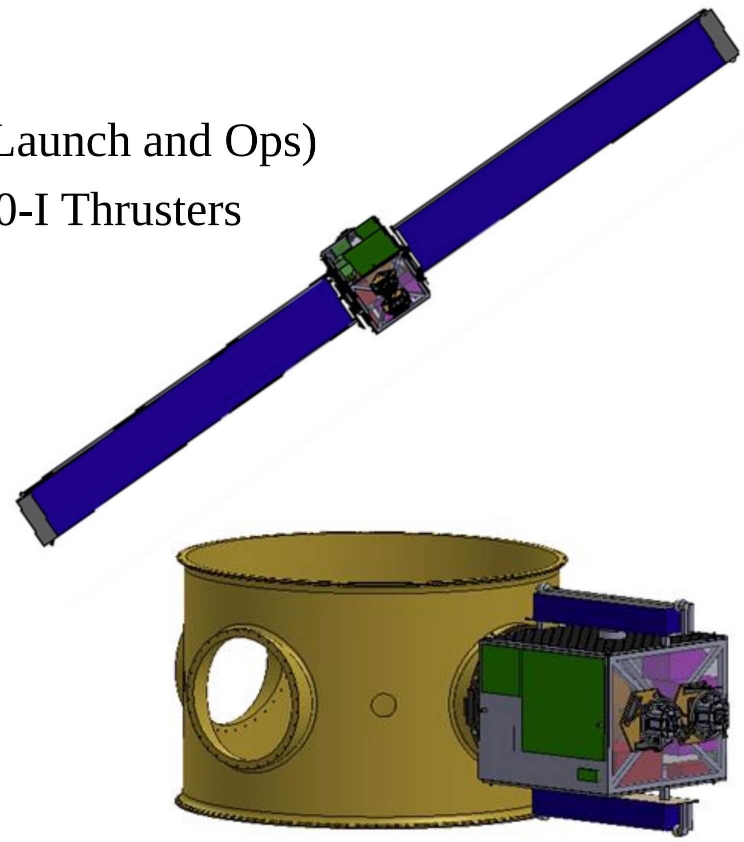
The technology can be enabling for a wide range of future commercial, academic, DoD and NASA HEOMD and SMD missions.

Discovery Mission SmallSat – NEA Orbiter

Detailed COMPASS Study for NEA Orbiter with “Discovery” science payload

- Deployment from GTO, ~10km/s post-launch ΔV
- Iodine enabling due to density over xenon
- Total life cycle cost w/o instruments ~$130M (w/Launch and Ops)
- Leveraged 2 x 800W ROSA wings w/ 2x BHT-600-I Thrusters

Main Subsystems	Predicted Mass (kg)	Aggregate Growth (%)
i2Hall Spacecraft	272	
SEP Bus	272	7%
Science Payload	13	0%
Attitude Determination and Control	5	3%
Command & Data Handling	8	28%
Communications and Tracking	7	10%
Electrical Power Subsystem	29	25%
Thermal Control (Non-Propellant)	22	15%
Propulsion (Chemical Hardware)	5	0%
Propellant (Chemical)	1	0%
Propulsion (EP Hardware)	25	10%
Propellant (EP)	131	0%
Structures and Mechanisms	27	17%
Element 1 consumables (if used)	0	
Estimated Spacecraft Dry Mass (no prop,consum)	139	14%
Estimated Spacecraft Wet Mass	272	
. Growth Calculations SEP Bus		Total Growth
Dry Mass Desired System Level Growth	142	30%
Additional Growth (carried at system level)		14%
Total Wet Mass with Growth	287	

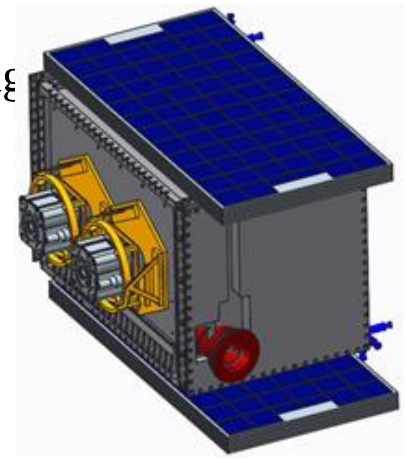


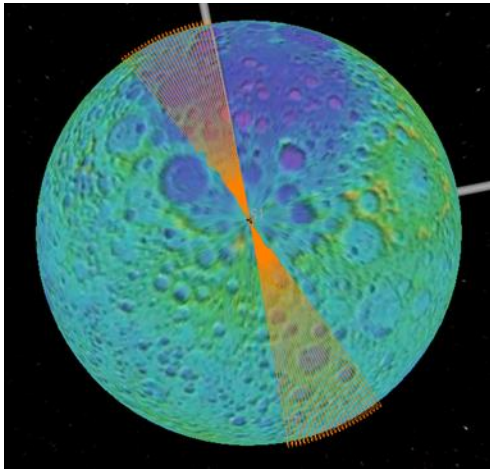
High science value enabled by iodine secondary GTO deployment .

Discovery Mission SmallSat – Lunar Orbiter

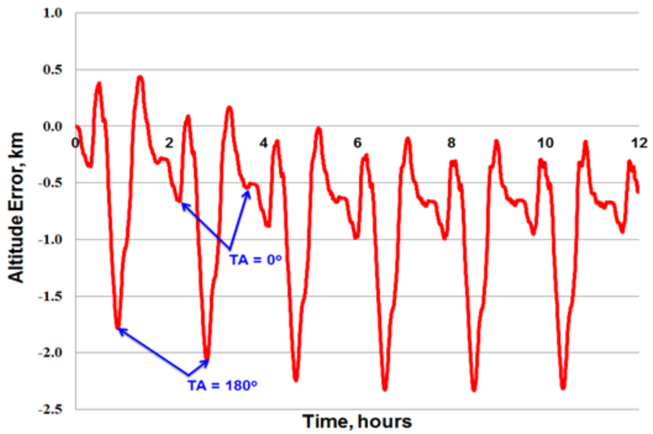
Detailed ACO Study for Lunar Orbiter with “Discovery” science payload

- Deployment from GTO
- Iodine enabled 100x5km orbit station-keeping
- Total life cycle cost ~$150M
- Leveraged 2x BHT-600-I Thrusters





Mass Estimation List (MEL)		Basic Mass (kg)	ave MGA (%)	Predicted Mass (kg)
1.0	Structures	21.2	30%	2756%
2.0	Mechanisms - In Subsystems			0.0
3.0	Thermal	4.8	0.3	6.0
4.0	Power	90.6	0.2	107.2
5.0	Guidance Navigation & Control (GN&C)	8.4	0.1	9.8
6.0	Communications	6.8	0.3	8.5
7.0	Command and Data Handling (C&DH)	7.9	0.3	10.1
8.0	Propulsion	17.3	0.1	17.3
Dry Mass		157.0	16%	186.6
9.0	Insturments	10.1	0.2	12.2
10.0	Non-Propellant Fluids	0.0	0%	0.0
Inert Mass		167.2	16%	198.7
11.0	Propellant			
11.1	Nitrogen (Cold Gas)	9.4	5%	9.9
11.2	Iodine	87.0	3%	89.6
Total Mass		263.6		298.2

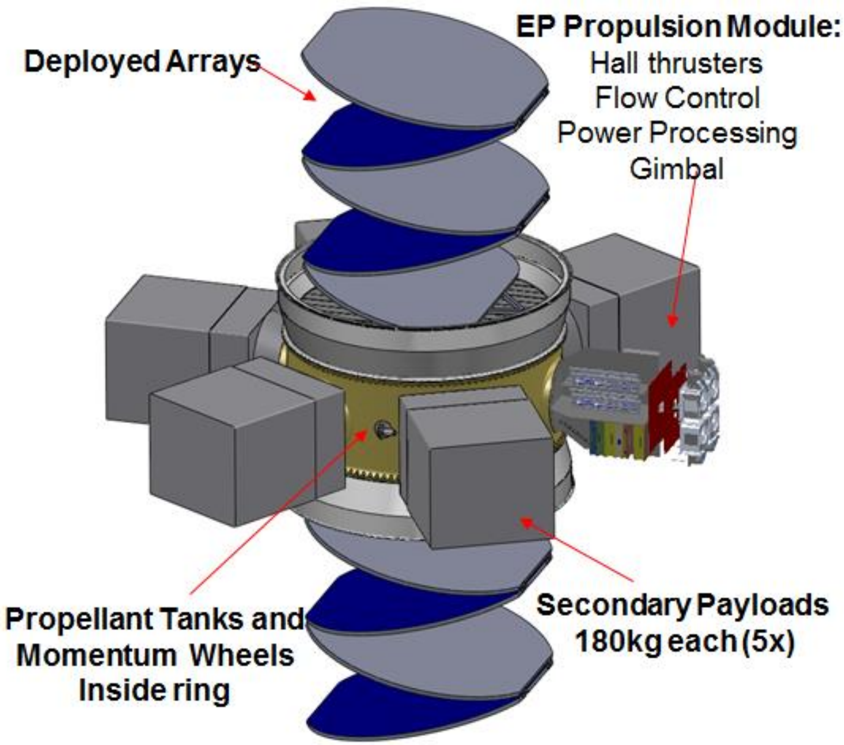


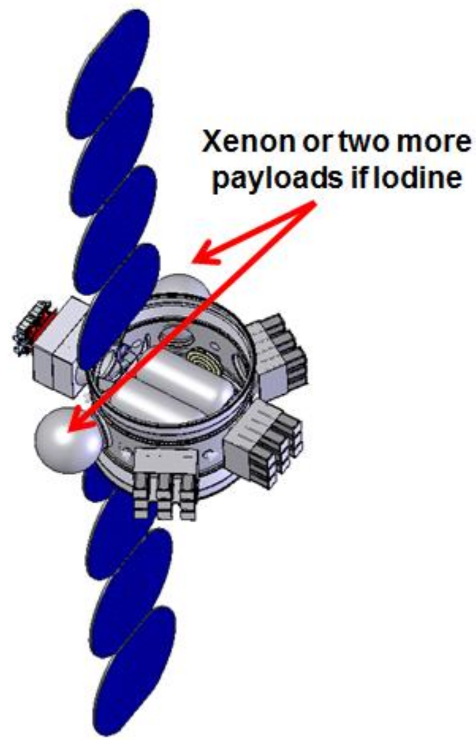
Iodine / Electric Propulsion enables high value lunar orbiter science despite multiple previous lunar missions.

Orbit Transfer Vehicles

The direct replacement of xenon for iodine will significantly increase ΔV capability or enable additional payloads on the carrier vehicle.

- $10M Revenue increase per payload to LEO



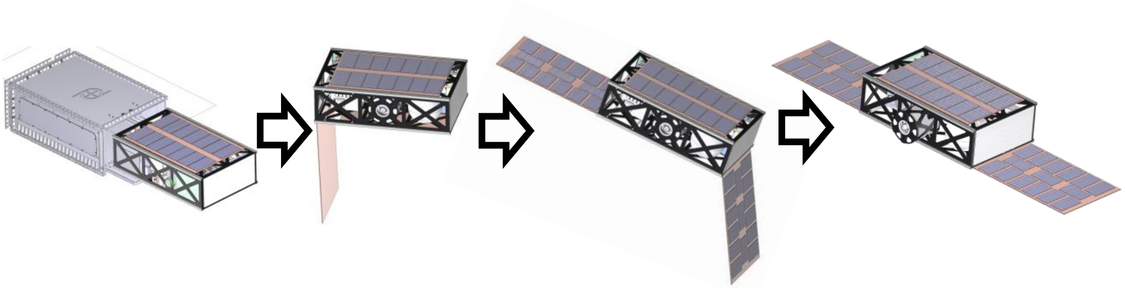


Iodine can increase capability and revenue for orbit transfer vehicles

Mission ConOps

LAUNCH

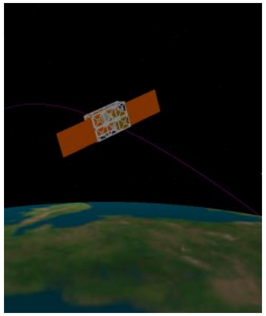
DEPOLOY



- Ride-share launch opportunity
- Most likely to sun-synch orbit

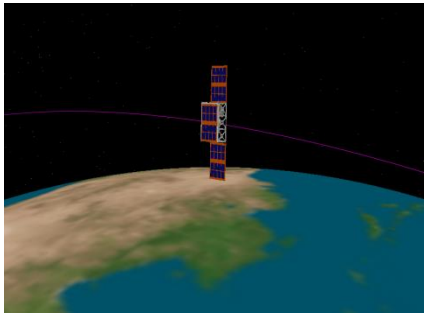
- Deployable solar arrays for power production
- Deployable thrust assembly to support management of internal thermal environment

CHECK OUT



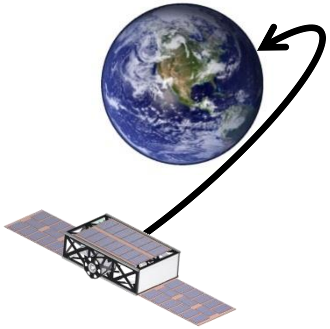
- Evaluate tip-off moments
- Arrest initial rotation with magnetic torquers

OPERATIONS



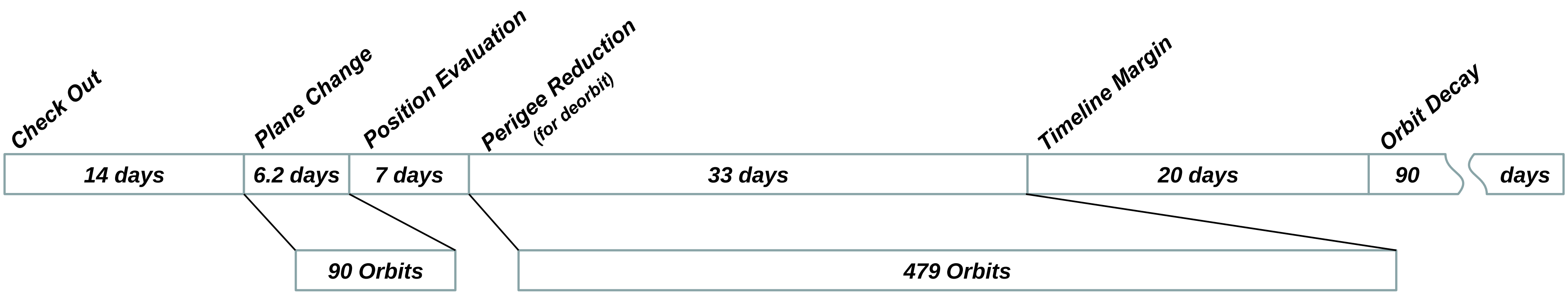
- Support tech demo through inclination change and perigee lowering operations
- See next chart for timeline details

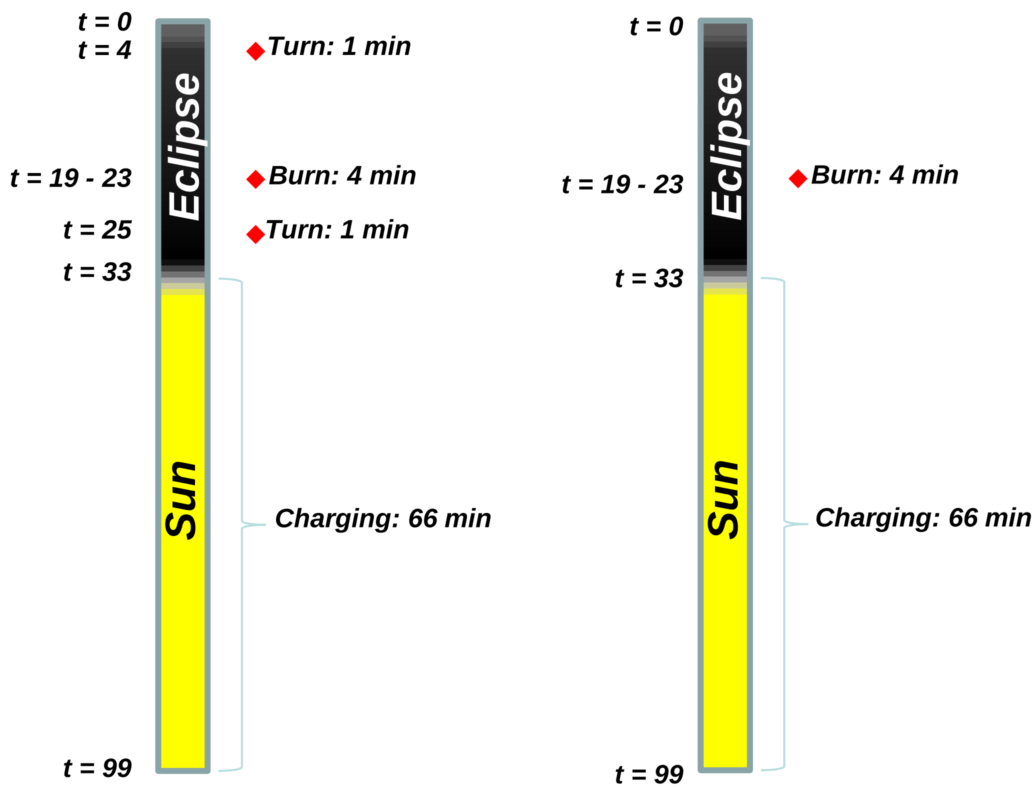
DEORBIT



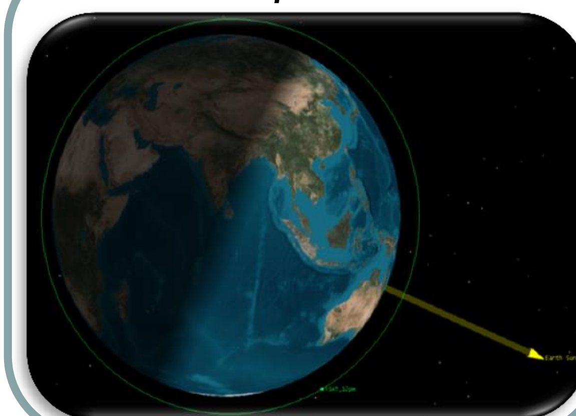
- Natural drag interaction will result in deorbit after perigee is lowered

Mission Timeline





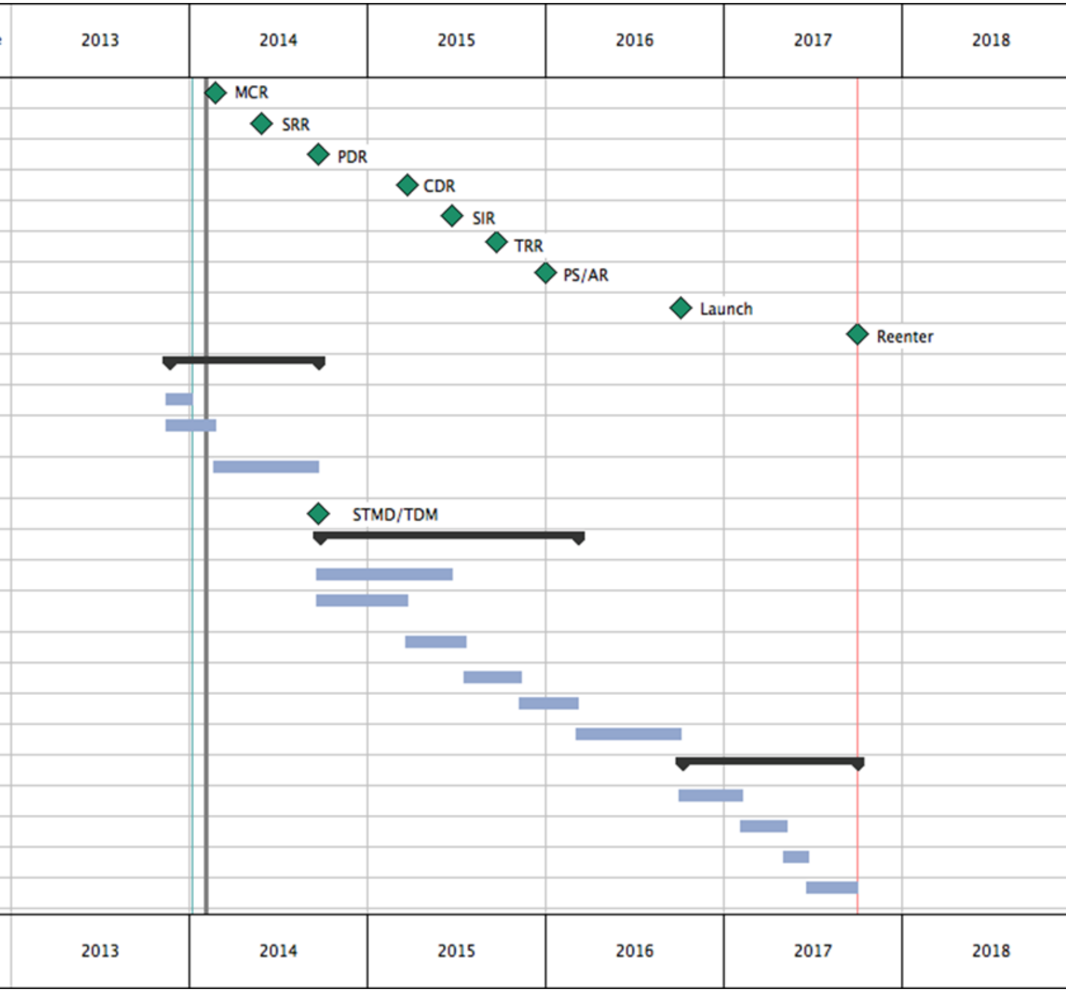
Sample Orbit



NOTE: All burns performed during eclipse to maximize favorable thermal conditions during burn and maximize charge time during solar exposure

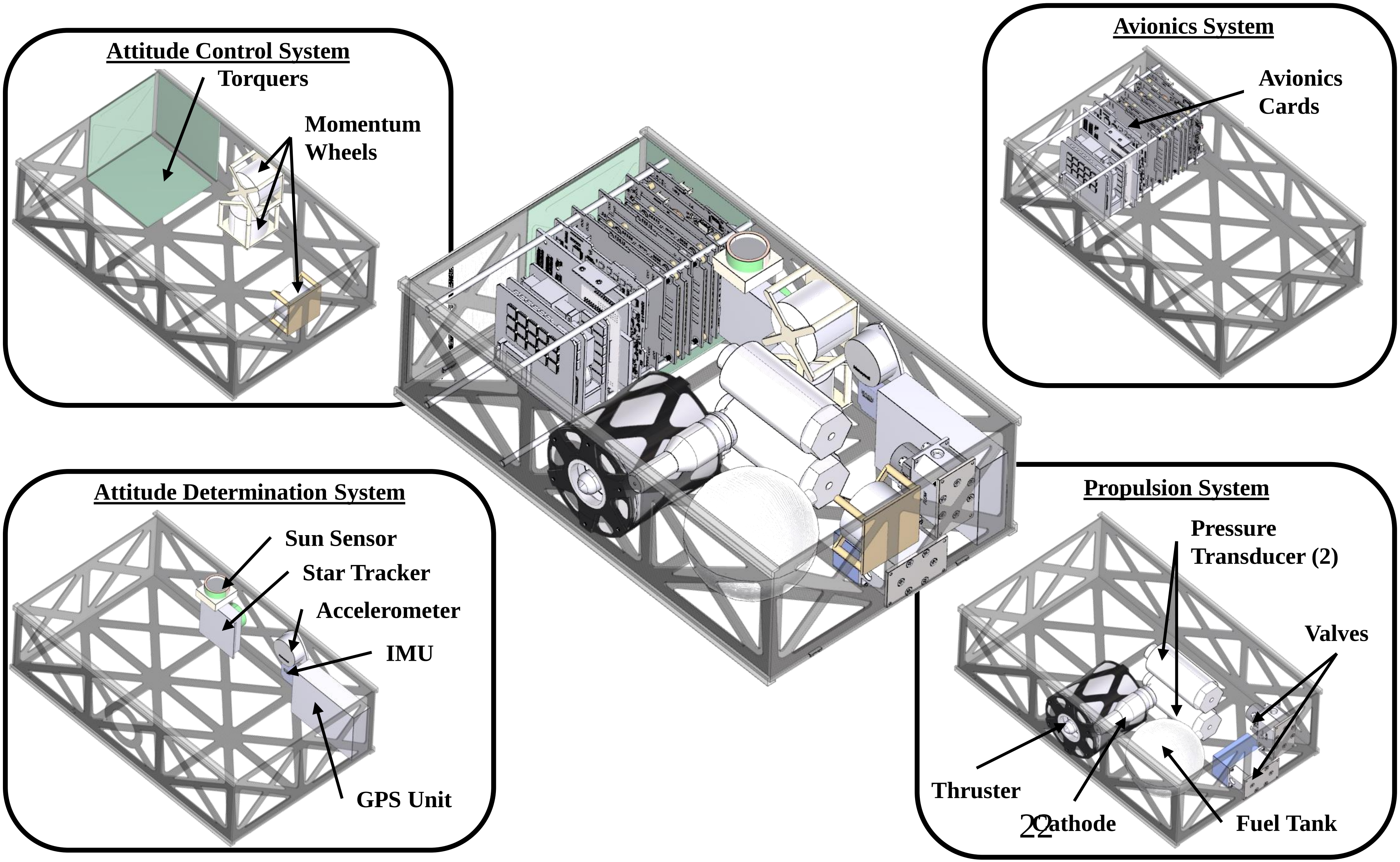
Development Schedule

Activity Name	Duration (Work Days)	Start Date	Finish Date
MCR	0.00	2/24/14	2/24/14
SRR	0.00	5/28/14	5/28/14
PDR	0.00	9/22/14	9/22/14
CDR	0.00	3/23/15	3/23/15
SIR	0.00	6/22/15	6/22/15
TRR	0.00	9/21/15	9/21/15
PS/AR	0.00	1/1/16	1/1/16
Launch (target)	0.00	10/3/16	10/3/16
Reenter (estimated)	0.00	10/2/17	10/2/17
Formulation	**221.00**	**11/18/13**	**9/22/14**
ACO Studies	36.00	11/18/13	1/6/14
Conceptual Design/Develop MCR Products	71.00	11/18/13	2/24/14
Preliminary Design/Develop SRR/PDR Products	151.00	2/24/14	9/22/14
ATP from STMD/TDM	0.00	9/22/14	9/22/14
Implementation	**382.00**	**9/22/14**	**3/8/16**
Procure Long Lead Items	196.00	9/22/14	6/22/15
Detailed Design/Develop CDR Products	131.00	9/22/14	3/23/15
Fabricate/Assemble	86.00	3/23/15	7/20/15
Integrate	84.00	7/20/15	11/12/15
Testing	84.00	11/12/15	3/8/16
Development Schedule Margin	150.00	3/8/16	10/3/16
Mission Operations	**261.00**	**10/3/16**	**10/2/17**
Check Out/Propulsion Demonstration	93.00	10/3/16	2/8/17
Science Mission	64.00	2/8/17	5/8/17
Perigree Reduction (for deorbit)	34.00	5/8/17	6/22/17
Timeline Margin	73.00	6/22/17	10/2/17

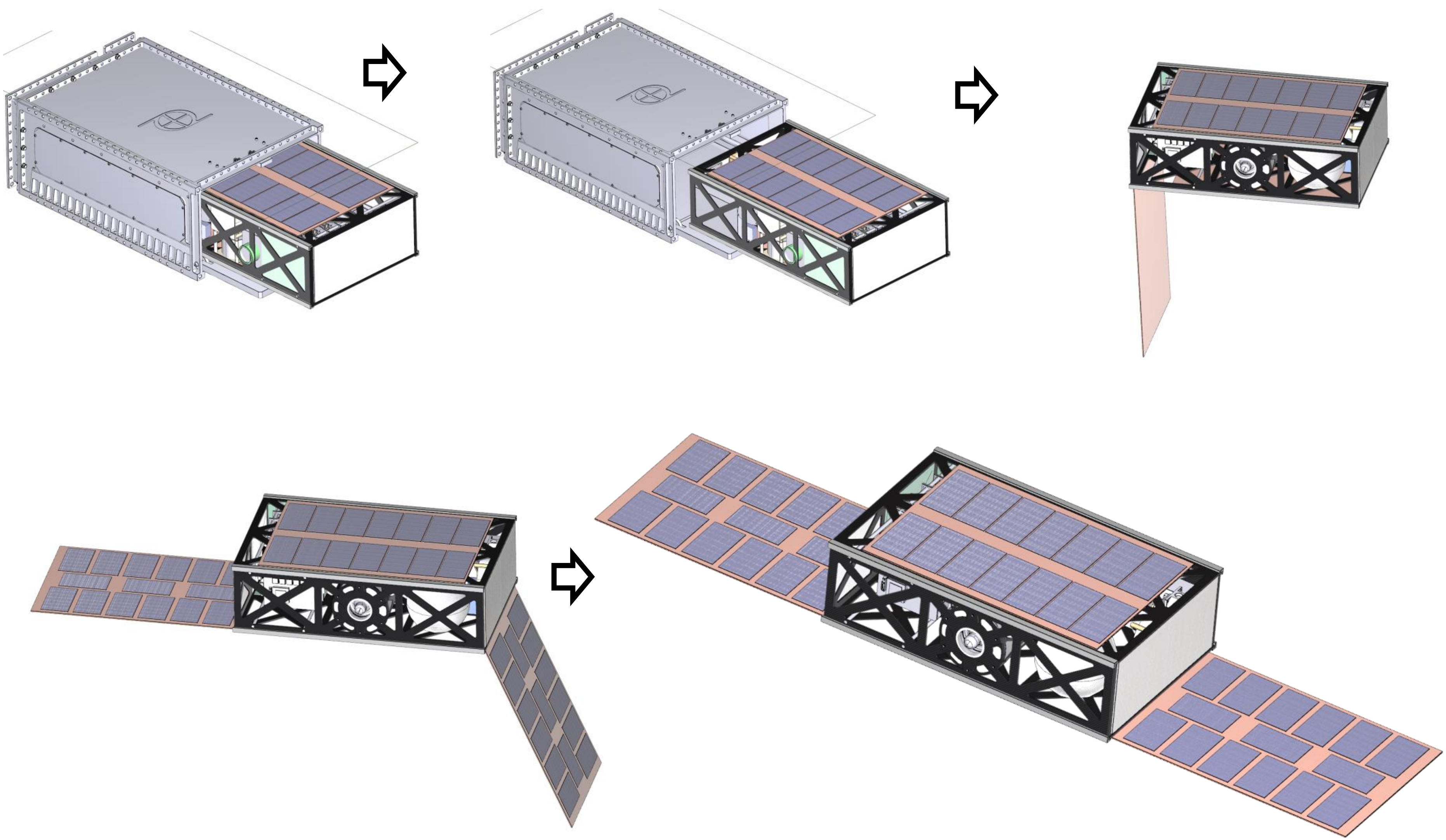


The iSAT Project is on an aggressive schedule for FY17 launch.

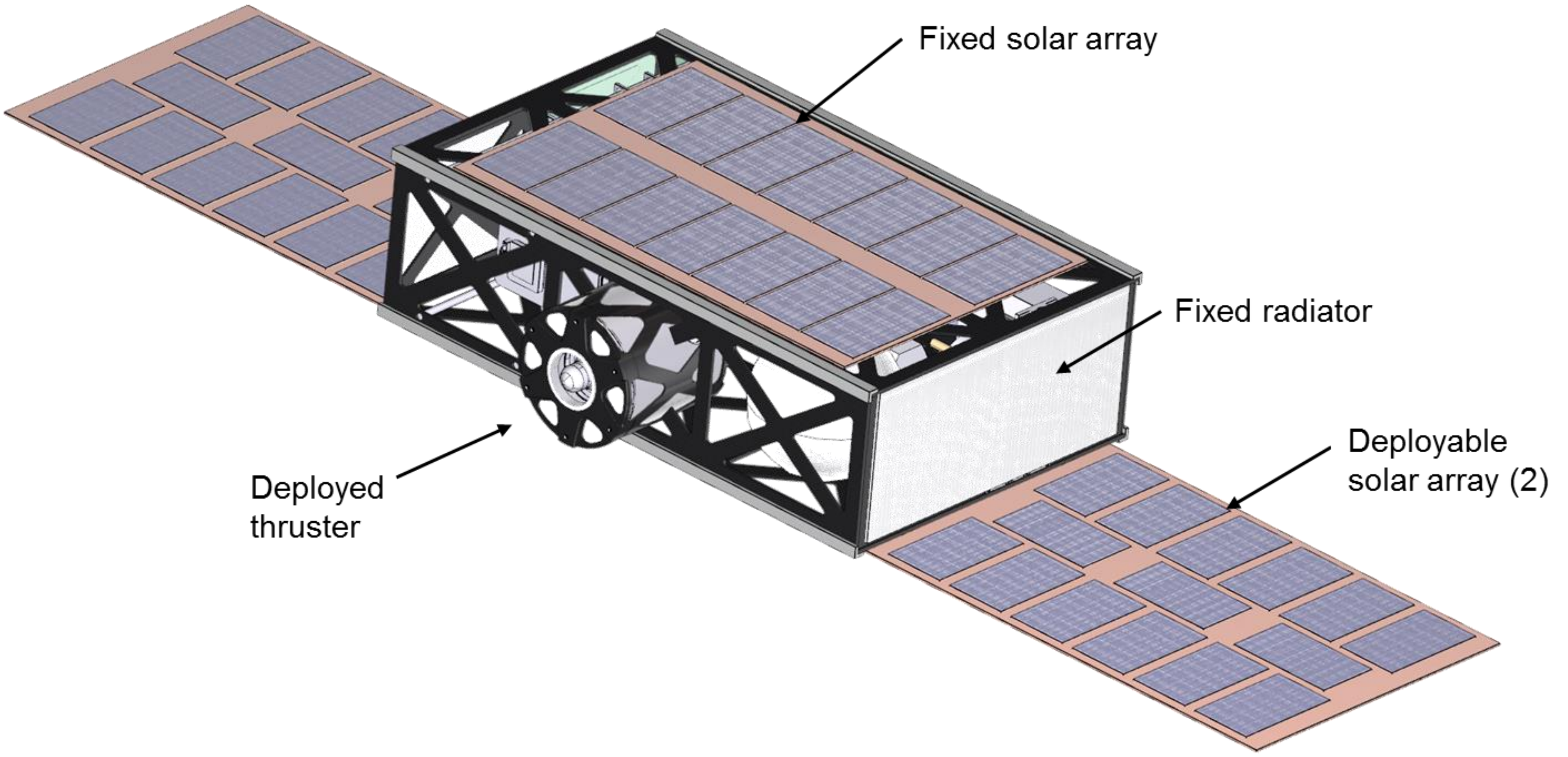
Configuration-6U



Deployment-6U



Deployed-6U


Fixed solar array
Fixed radiator
Deployable
solar array (2)
Deployed
thruster

6U LEO Mission

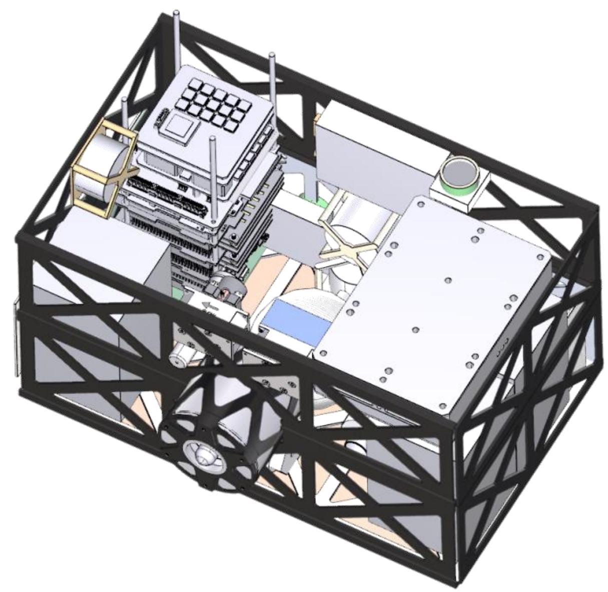
iSAT Mass Estimation List (MEL) 6U Baseline		Basic Mass (kg)	MGA (%)	MGA (kg)	Predicted Mass (kg)
1.0	Structures	1.100	30%	0.330	1.430
2.0	Mechanisms	0.100	30%	0.030	0.130
3.0	Thermal	0.334	30%	0.100	0.434
4.0	Power	2.040	30%	0.612	2.652
5.0	Guidance Navigation & Control (GN&C)	1.453	10%	0.145	1.598
6.0	Communications	0.090	6%	0.005	0.095
7.0	Command and Data Handling (C&DH)	0.304	15%	0.047	0.351
8.0	Propulsion	3.846	25%	0.965	4.811
Dry Mass		9.267	24%	2.235	11.501
9.0	Payload				0.000
10.0	Non-Propellant Fluids	0.000	0%	0.000	0.000
Inert Mass		9.267	24%	2.235	11.501
11.0	Propellant (Solid Iodine)	0.180		0.000	0.180
iSAT 6U Baseline Total Mass		9.447		2.235	11.681

6U mission must come in at less than 10 kg. Already outside the box.
No payload accommodations for increased extensibility.

6U Demonstrator high risk early in the concept phase.
Not selected for Baseline.

Interplanetary ConOps

- Interplanetary mission will require entirely different con-ops than the LEO missions
- Assume EM-1 Launch, Deployment will occur at +C3
- Rotation damping and initial orientation will be achieved through the use of reaction wheels and cold-gas thrusters
- Flight orientation and thruster duty cycle will be dependent on destination
  - Will most likely require periods of thrust followed by periods of charging
  - Destination (and resulting trajectory) will determine whether charging can occur without spacecraft rotation
- Science operations will be dependent on destination



Iodine Hall w/ Micro Gimbal may eliminate/mitigate ACS requirements.

12U LEO Interplanetary MEL

iSAT Mass Estimation List (MEL)		Basic Mass (kg)	MGA (%)	MGA (kg)	Predicted Mass (kg)
1.0	Structures	1.601	30%	0.480	2.081
2.0	Mechanisms	0.100	30%	0.030	0.130
3.0	Thermal	0.364	28%	0.103	0.467
4.0	Power	2.952	30%	0.898	3.850
5.0	Guidance Navigation & Control (GN&C)	2.766	24%	0.677	3.443
6.0	Communications	2.060	3.00%	0.062	2.122
7.0	Command and Data Handling (C&DH)	0.254	20%	0.051	0.305
8.0	Propulsion	3.846	25%	0.965	4.811
Dry Mass		13.942	23%	3.265	17.207
9.0	Payload	2.000	0%	0.000	2.000
10.0	Non-Propellant Fluids	0.000	0%	0.000	0.000
Inert Mass		15.942	20%	3.265	19.207
11.0	Propellant (Solid Iodine)	0.793		0.000	0.793
iSAT Total Mass		16.735		3.265	20.000

12U Interplanetary mission mass requirement < 14 kg.
Additional challenges remained for ACS and communication.

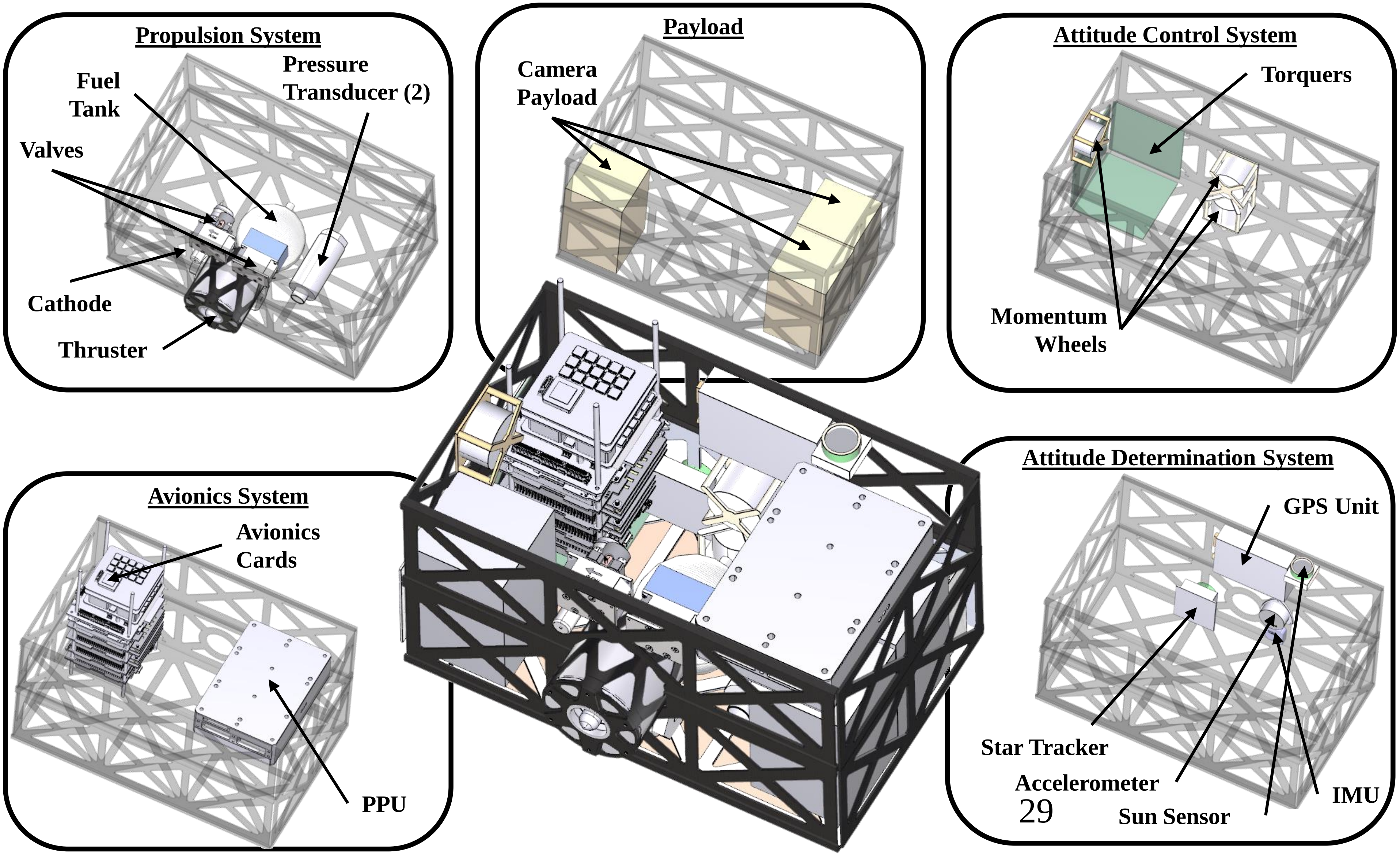
12U Interplanetary exceeds EM-1 mass requirement.
Not selected for baseline.

12U LEO Design Reference Mission

iSAT Mass Estimation List (MEL)		Basic Mass (kg)	MGA (%)	MGA (kg)	Predicted Mass (kg)
1.0	Structures	1.601	30%	0.480	2.081
2.0	Mechanisms	0.100	30%	0.030	0.130
3.0	Thermal	0.334	30%	0.100	0.434
4.0	Power	2.052	30%	0.616	2.668
5.0	Guidance Navigation & Control (GN&C)	1.518	10%	0.152	1.670
6.0	Communications	0.090	6.00%	0.005	0.095
7.0	Command and Data Handling (C&DH)	0.324	16%	0.053	0.377
8.0	Propulsion	3.846	25%	0.965	4.811
Dry Mass		9.864	24%	2.401	12.265
9.0	Payload	6.000	0%	0.000	6.000
10.0	Non-Propellant Fluids	0.000	0%	0.000	0.000
Inert Mass		15.864	15%	2.401	18.265
11.0	Propellant (Solid Iodine)	0.720		0.000	0.720
iSAT Total Mass		16.584		2.401	18.985

12U LEO option is the only preliminary concept with margin; lowest risk and selected as the Baseline.

System Architecture



Payload Opportunities

The iSAT spacecraft will be deployed in LEO with significant propulsion capability

- The baseline mission will allow for science at 850km down to 250km altitudes
- The baseline layout is based on carrying **THREE** AF IR imager payloads
  - 2W, 2kg and 8cm x 8cm x 13cm each
- The baseline mission only carries **ONE** AF IR imager

The iSAT project would like to carry a plasma diagnostic package

- Flight validate the plasma environment
- Diagnostic is TBD, undefined and unfunded
- A dual Langmuir probe system is leading candidate

A third payload is under consideration from NASA Ames Research Center

- Camera for spacecraft interactions assessment
- Selfie-Sat capability for outreach

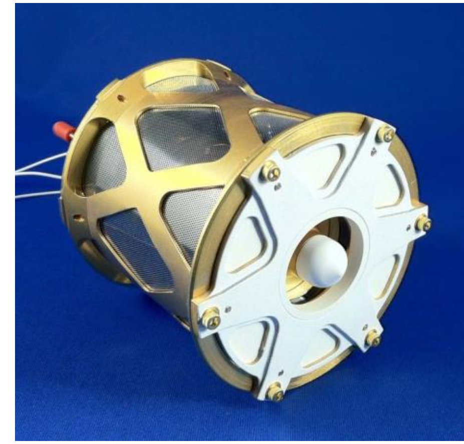
The iSAT mission is attempting to balance complexity and return on investment.

Payloads are excellent requirements drivers to ensure iSAT is more than a tech demo, but an extensible system.

Propulsion

BHT-200-I Thruster:

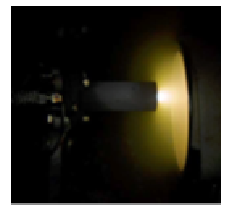
- Heritage to TacSat-2
    - Most studied thruster since SPT-100
- Material changes for iodine compatibility



Cathode:

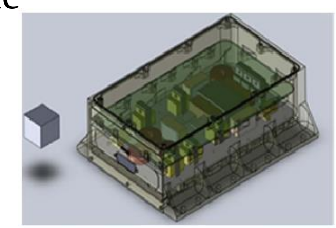
LaB6 and Electric Cathodes under consideration

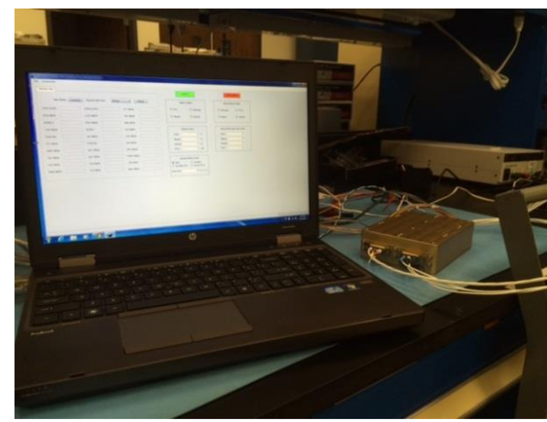
- Minimize power requirements
- Both successfully operated on iodine



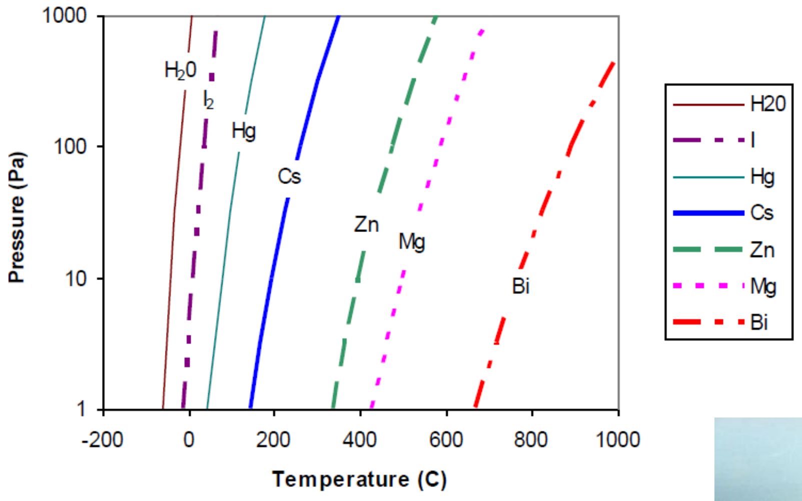
Compact PPU:

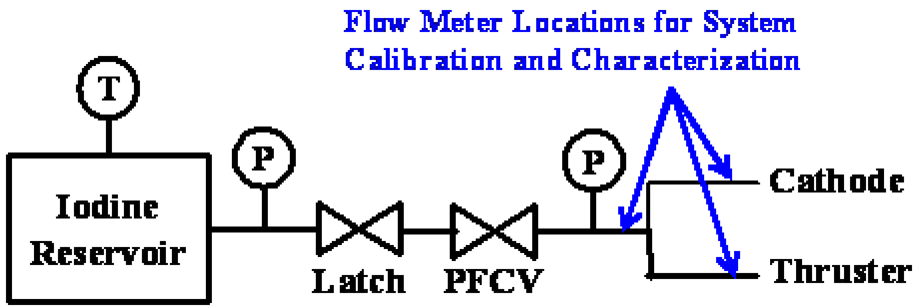
- 3rd PPU iteration ongoing
- Based on BPU-600
    - 80% Mass reduction
    - 90% Volume reduction

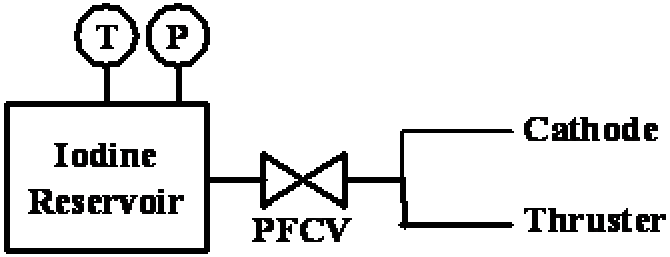


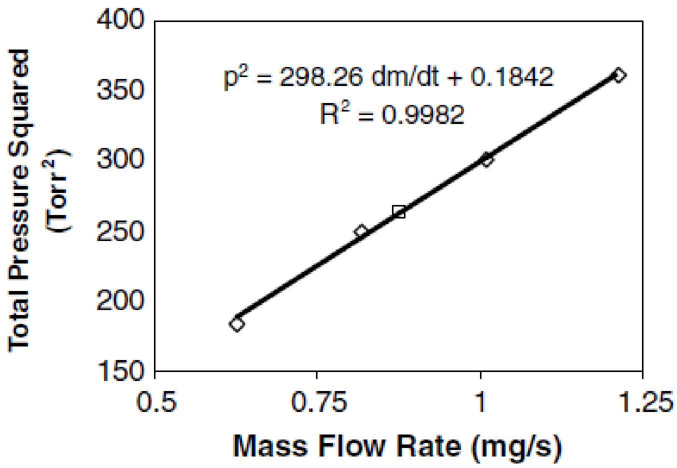


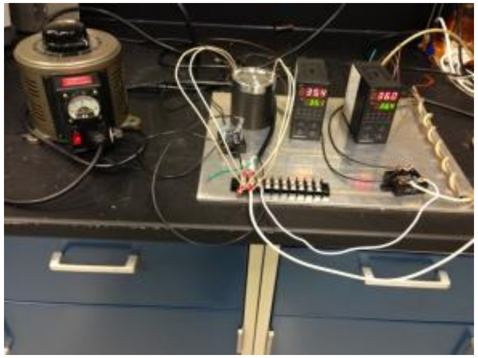
Feed System & DCIU

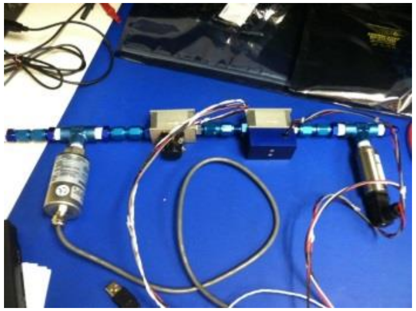






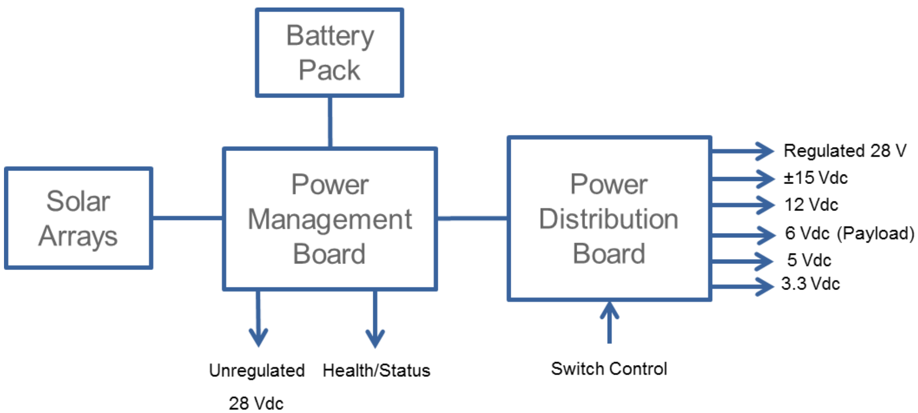


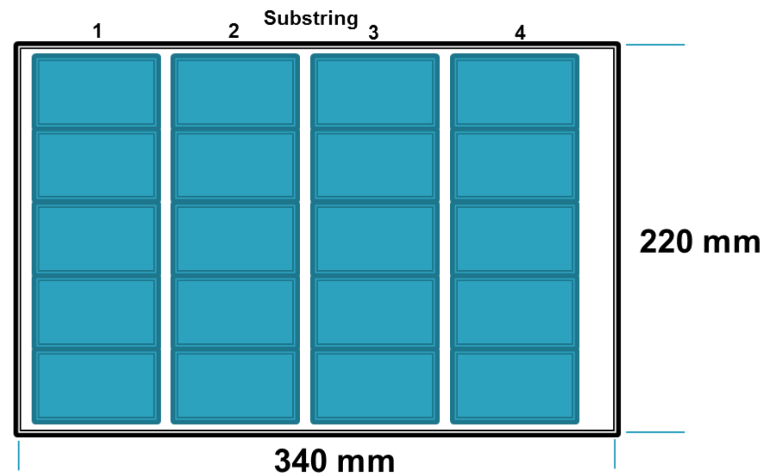




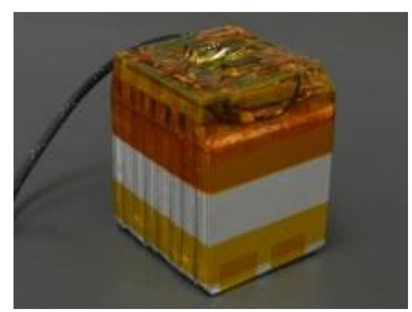
Power

In-house custom power management and power distribution boards
In-house custom solar panels and in-house custom battery



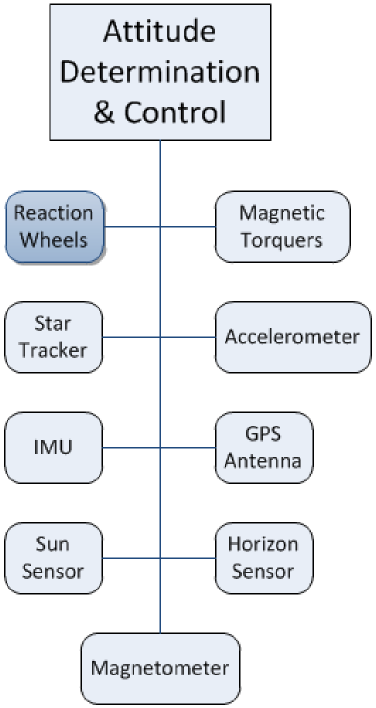


3 Panel Solar Array Configuration
- One fixed; two deployed
- Each panel consists of 20 Ultra Triple Junction Solar Cells (Spectrolab 28.3% UTJ) wired in a 15S4P configuration.
  - Three panels, each with 4 substrings of 5 cells each; each panel's corresponding substring in series for a total of 15 cells per string; each string in parallel
  - Cells 28.3% efficient (BOL, 28^{0}C)
  - Cell area 26.62 cm^2 (3.95 cm x 6.89 cm)
  - V_{oc} = 39.9 V
  - V_{mp} = 35.2 V (BOL, 28 ^{0}C); 30.2 V (BOL, 80 ^{0}C)
  - I_{mp} = 0.43 A per string or 1.72 A total
  - **Power = 60.5 W (BOL, 28 ^{0}C); 51.9 W (BOL, 80 ^{0}C)**

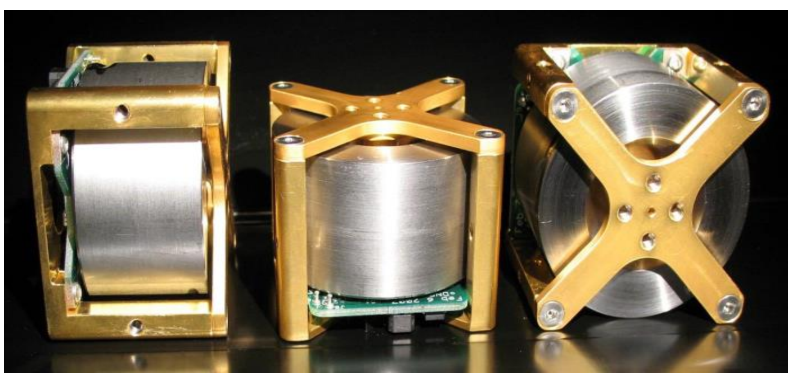


High power density / high current battery back
- Lithium Polymer
- High TRL, flown on multiple CubeSat and AFRL SmallSat
- Continuous current = 2-5C
- Energy Density = 130 – 200Wh/kg

Attitude Control



Component	Quantity	Power (per unit)	Mass (per unit)	Vendor, part #
Reaction Wheels (pitch/yaw/roll axes)	3	1.5 W (peak) 0.4 W (steady state)	0.185 kg	Sinclair (RW-0.03-4)
Star Tracker	1	1.0 W (peak) 0.5 W (avg)	0.085 kg	Sinclair (ST-16)
Inertial Measurement Unit (IMU)	1	0.1 W (3.3 V @ 30 mA)	0.007 kg	Epson (M-G350-PD11)
Magnetic Torquers	3	0.2 W	0.065 kg	TBD
GPS	1	1 W	< 0.2 kg	Spacequest
Accelerometer	1	0.5 W	0.075 kg	Honeywell (QA-3000)
Sun Sensor	1	0.13 W (peak) 0.04 W (avg)	0.034 kg	Sinclair (SS-411)
Magnetometer	1	0.4 W	0.2 kg	SSBV
Earth Horizon Sensor	1	0.36 W	0.085 kg	Maryland Aerospace (MAI-SES)



Disturbance Torque	Axis	Angular Momentum (mN-m-s)	
		During 10min Maneuver	During Orbit
Thrust Vector Misalignment	Y/Z	21.6	-
Thruster Magnetic Dipole	Y/Z	30	-
Thruster Swirl Torque	X	6	-
Gravity Gradient	-	-	1.3
Aerodynamic Drag	-	-	0.0052
Solar Radiation Pressure	-	-	0.15
Thruster-off residual magnetic dipole	Y/Z		7.2

Off the Shelf!

Communications

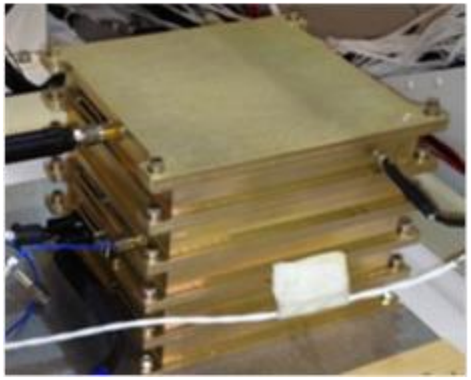
Baseline data volume ~6000 Mbytes/day - science payload generating 98% of the data

Baseline to use Near-Earth-Network; only 3/15 stations for the baseline

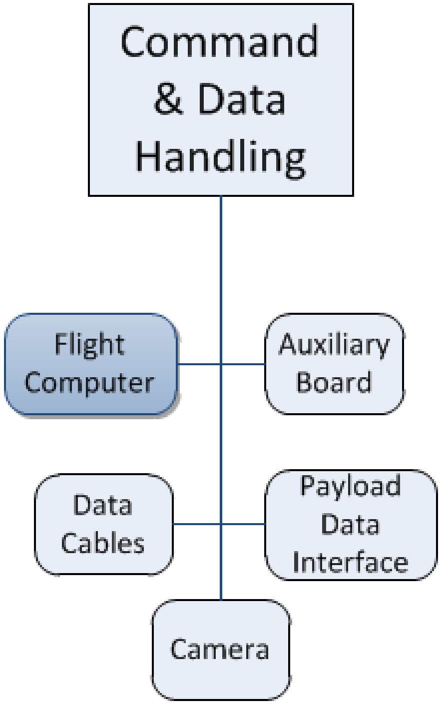
193 minutes of ground contact per day, assumes access for one-third of the available time conservatively estimate 64 minutes for data transfer

The data transfer requirement 12.7 Mbps leads to S-BD uplink and X-BD downlink architecture.

The stations chosen all have both S-BD and X-BD

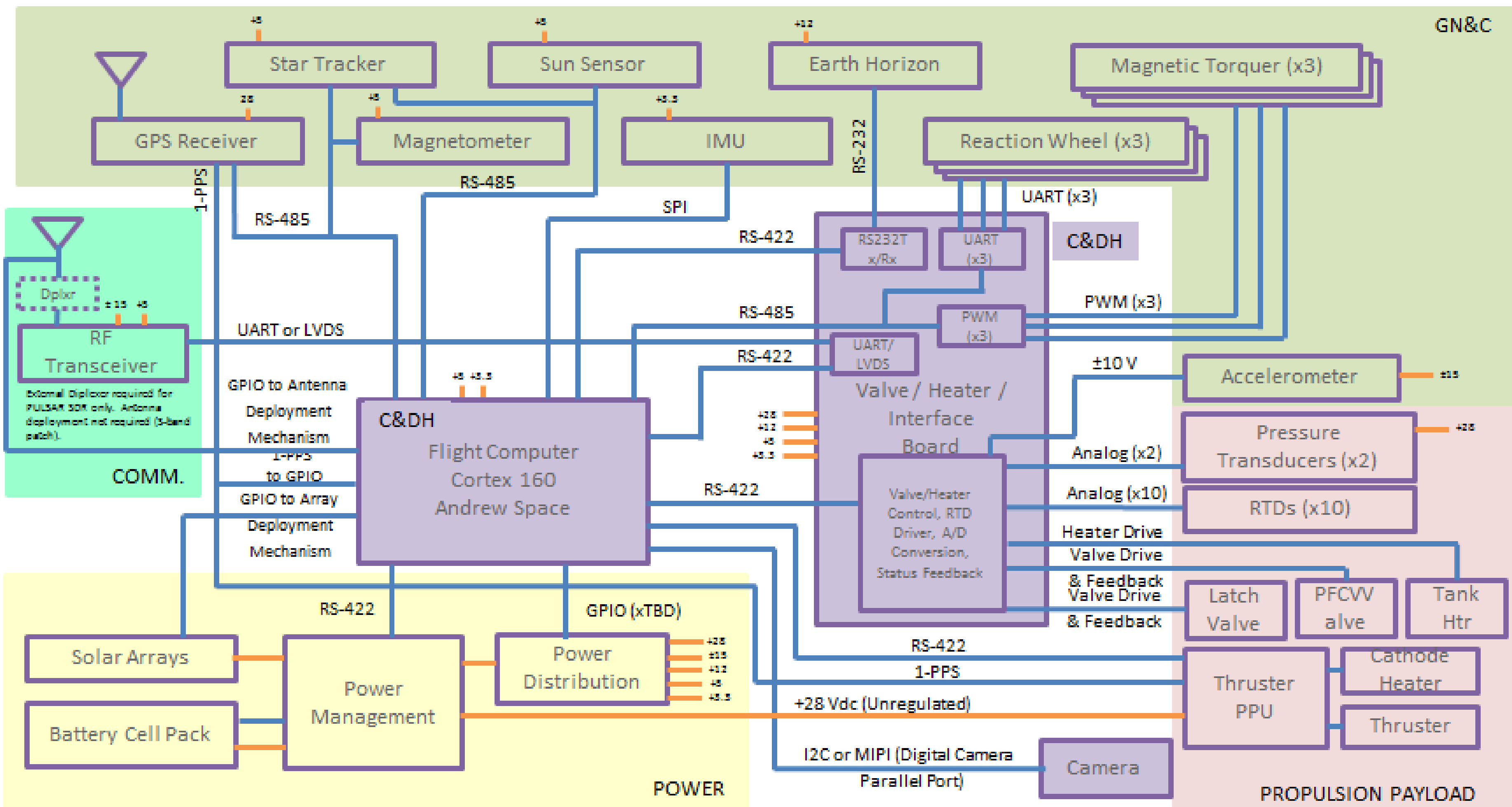


Command and Data Handling



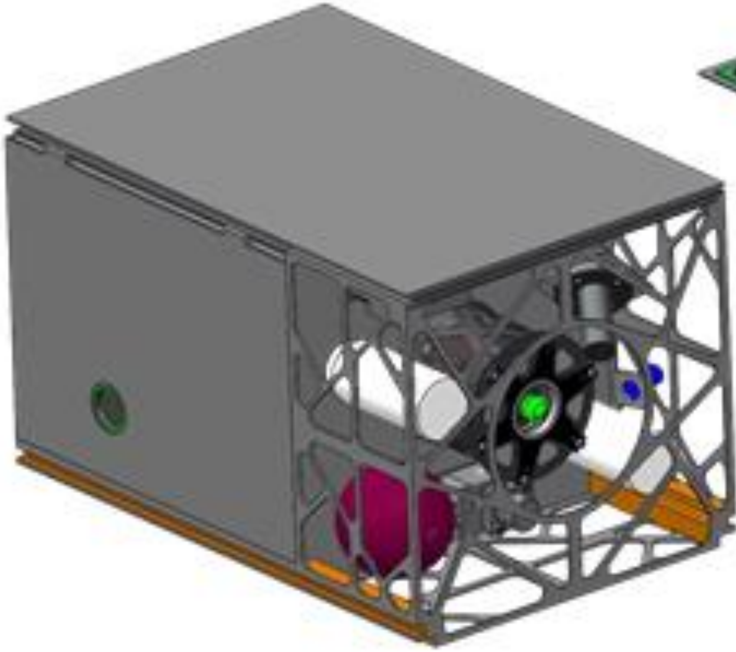
- Andrews Space Cortex 160
  - Processor and memory
    - Dual Power PC 405 (PPC405) processor with Linux Real Time Operating System (RTOS)
    - 2GB FLASH memory
  - Interfaces
    - Forty-four GPIO
    - Five RS-422
    - Three RS-485
    - Two SPI
    - Two I2C
    - Two parallel digital camera inputs
  - The following gaps exist
    - UART to each Reaction Wheel (x3)
    - Analog and Analog-to-Digital Conversion (ADC) for Accelerometer, Resistive Temperature Devices (RTDs, x10), and Pressure Transducers (x2)
      - Accelerometer (required for thruster performance measurement) has unique ±10 V analog output
    - PWM to each Magnetic Torquer (x3)
    - RS-232 to Earth Horizon Sensor
    - UART, LVDS, or RS-422 to payload(s)
    - UART or LVDS to RF transceiver
  - Design Life
    - 3 years
  - Radiation Tolerance
    - 15 krad of total ionizing dose
    - 37 MeV single event upset

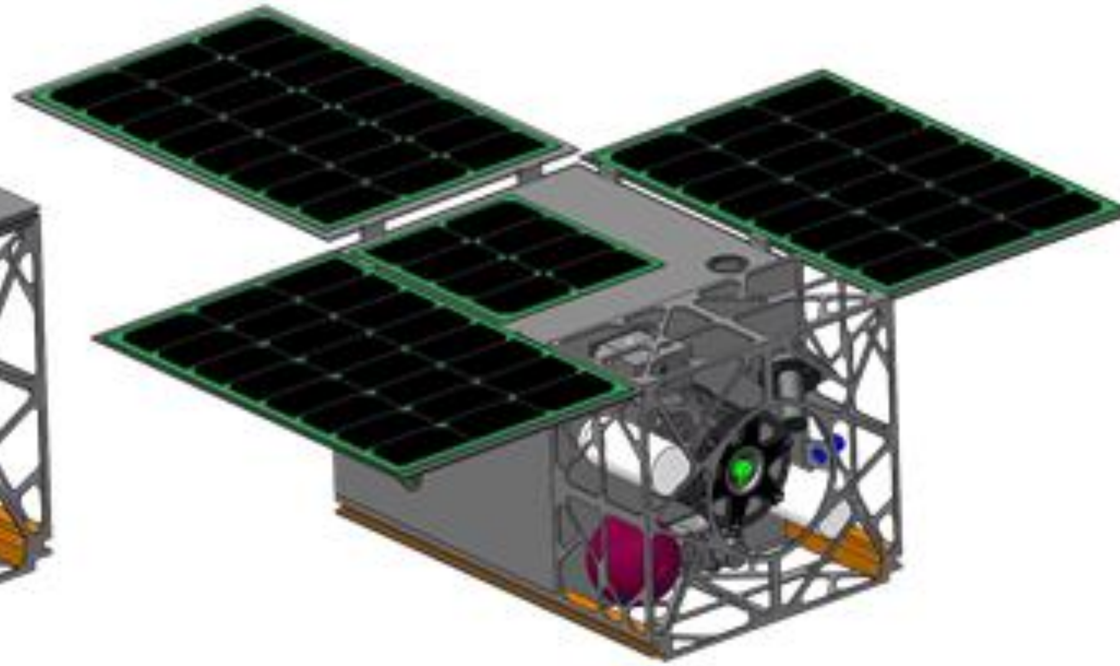
Command and Data Handling

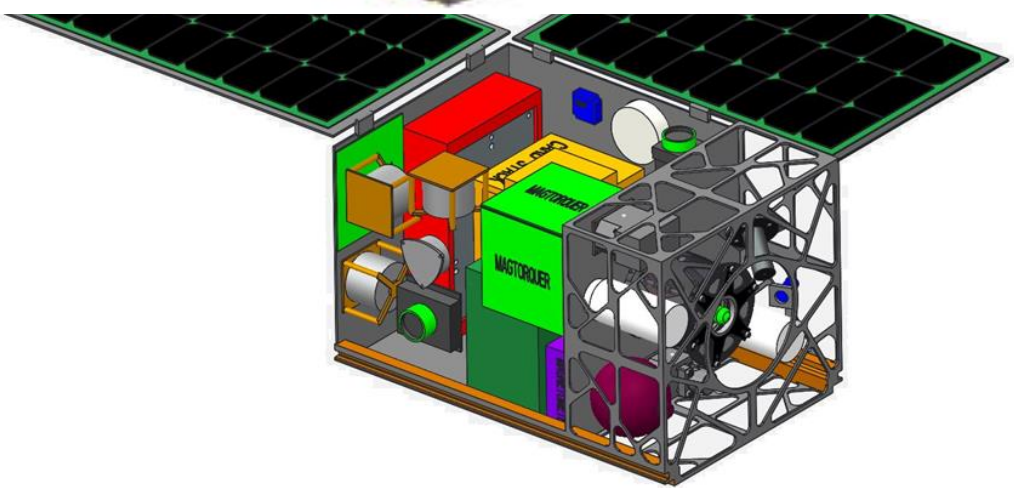


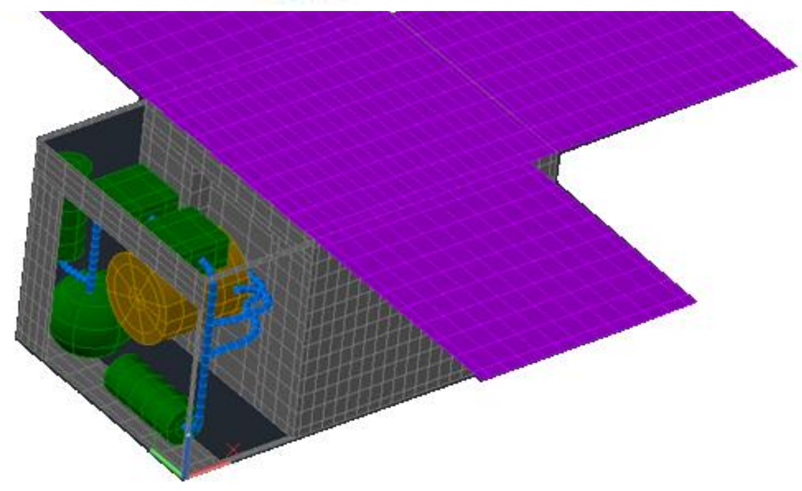
Unprecedented interfaces for a CubeSat

Design Update









Education and Public Outreach

Large number of outreach events

NASA Mission Needs → SmallSats → Technology Gaps → iSAT

NASA Mission Needs → Propulsion → Electric Propulsion → Iodine

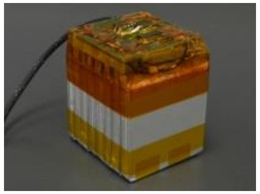
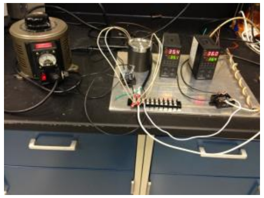
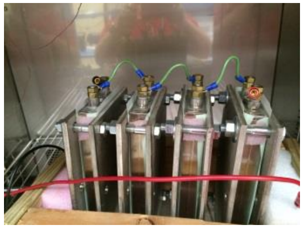
E&PO is a large part of the iSAT project.

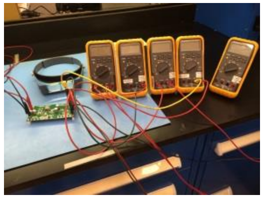
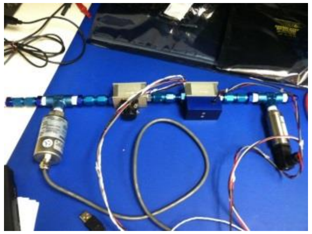
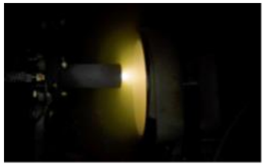
Progress to Date

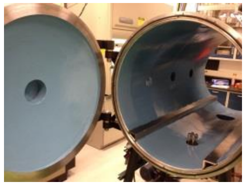
Successfully Completed MCR – February 28th
Table Top SRR – July 8, 2014

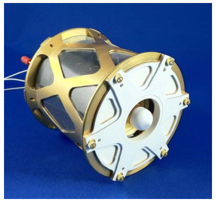
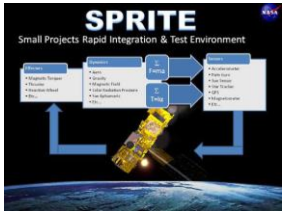
PDR and System Demonstration
– October 28, 2014

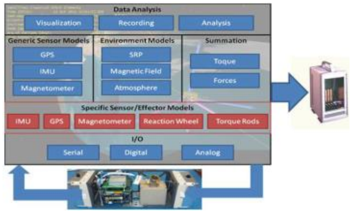
Hardware Status:
- BB Battery delivered – February 20, 2014
- BB EPS delivered – March 7, 2014
- BB DCIU delivered – March 27, 2014
- EM PPU Delivered – April 1, 2014
- EM Battery delivered – April 4, 2014
- EM Cathodes delivered – April 9, 2014 (two to GRC)
- EM Flight computer delivered – April 14, 2014
- EM Thruster Delivered – June 6, 2014
- Initial DCIU / Feed System Test – June 12, 2014
- Material testing initiated - Ongoing
- Integrated propulsion system check-out - Ongoing

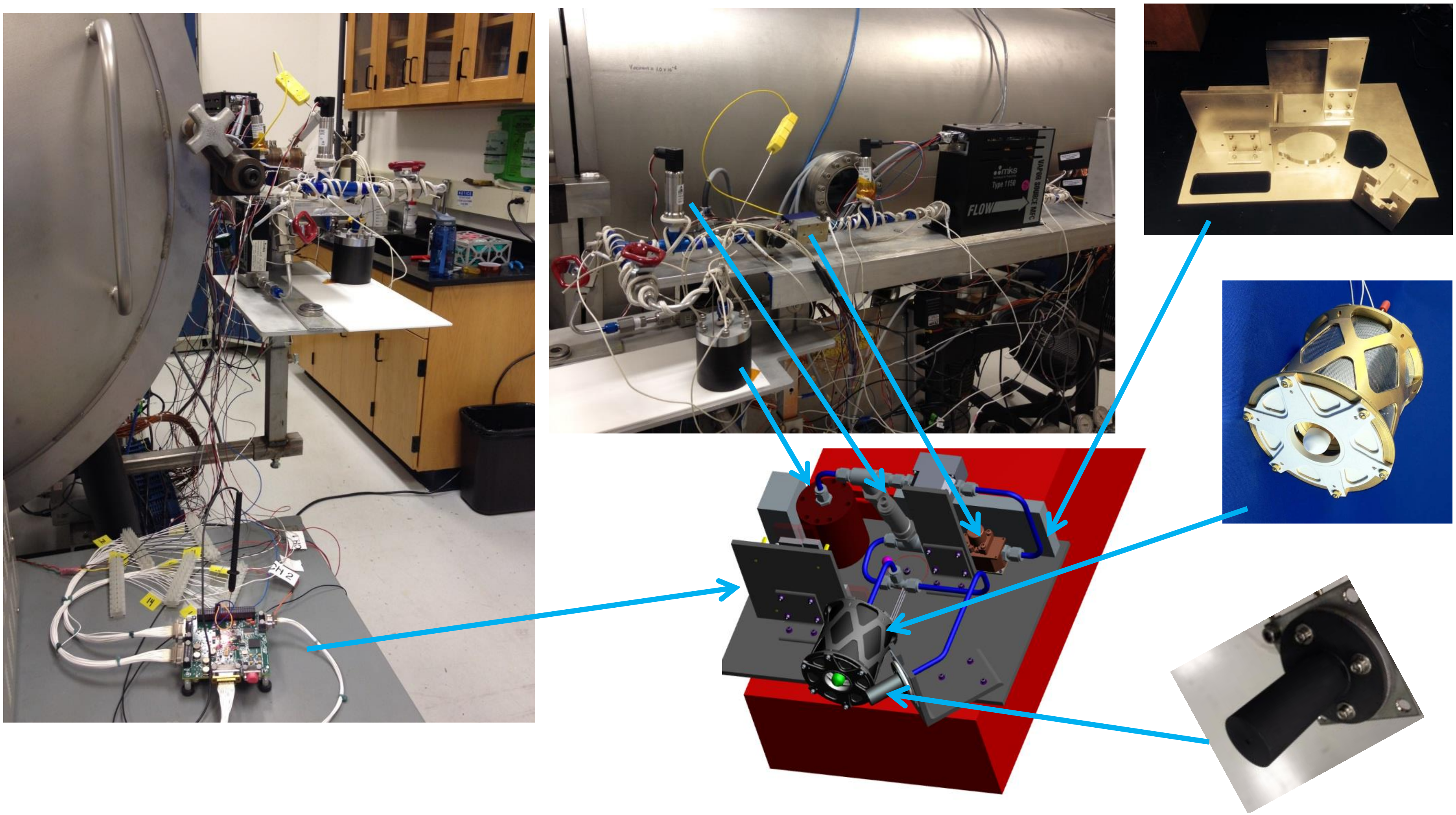


Significant hardware rich investments to reduce risk and simply integrate and fly as a technology demonstration mission.

Near-term Events

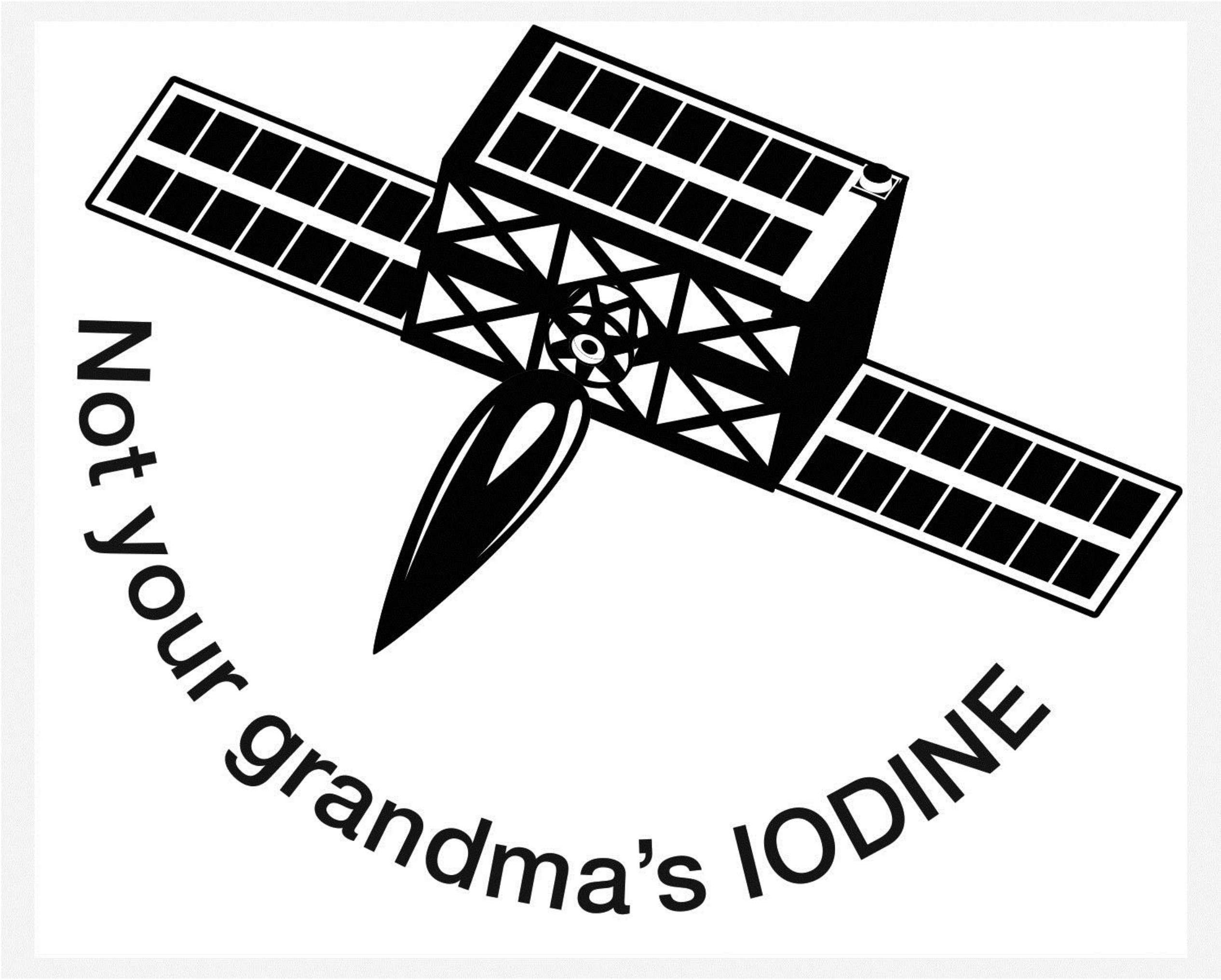


Near-term system performance characterization at NASA.

Closing Remarks

- The iSAT project is a fast pace high value iodine Hall technology demonstration mission
  - Partnership with NASA GRC and NASA MSFC with industry partner – Busek
- Propulsion remains a key limiting capability for SmallSats that Iodine can address
  - High ISP * Density for volume constrained spacecraft
  - Indefinite quiescence, unpressurized and non-hazardous as a secondary payload
- Iodine enables MicroSat and SmallSat maneuverability
  - Enables transfer into high value orbits, constellation deployment and deorbit
- Iodine may enable a new class of planetary and exploration class missions
  - Enables GTO launched secondary spacecraft to transit to the moon, asteroids, and other interplanetary destinations for ~$150M full life cycle cost including the launch
- ESPA based OTVs are also volume constrained and a shift from xenon to iodine can significantly increase the transfer vehicle ΔV capability or enable additional secondary payloads for increases revenue potential.
- The project team has made and continues to make significant progress towards risk reduction:
  - Flight-like operational feed system demonstration
  - DCIU development and testing
  - Integration propulsion system testing
  - Materials testing
  - Power control and distribution avionics design and development
  - Solar panel and battery testing
  - Preliminary flight software development
  - Structural design and analysis and thermal design and analyses.
- The iSAT mission is an approved project with PDR in October of 2014 and is targeting a flight opportunity in FY17.

Questions?



Acknowledgments

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